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Plant species selection by goats foraging on montane semi-natural grasslands and grazable forestlands in the Italian Alps

Gabriele Iussig,[1] Michele Lonati,[1] Massimiliano Probo,[1] Simon Hodge,[2] Giampiero Lombardi[1]

[1]Dipartimento di Scienze Agrarie, Forestali e Alimentari, University of Torino, Italy
[2]Faculty of Agriculture and Life Sciences, Lincoln University, Christchurch, New Zealand

Abstract

The interest for goats rearing has increased during last decades on the Italian Alps. However, feeding preferences by grazing goats have not undergone detailed investigation in extensive montane grazing systems. Our study aimed to assess plant species selection by integrating vegetation surveys with animal GPS tracking under two contrasting alpine vegetation communities: a semi-natural grassland (SG) and a grazable forestland (GF). Goats selected a high array of plant species (56 and 47 species in the SG and GF, respectively), but most of their diet was composed by a few species (ten species accounted for 95% and 91% of the total species intake in the SG and GF, respectively). The selection by goats seemed to be more species-dependent rather than functional group-dependent. Goats appeared to be less selective within a homogeneous herbaceous grassland, because they selected plant species proportionally to their abundance (P=0.05). Conversely, in a heterogeneous and stratified grazable forestland they showed a more pronounced preference for most of the browse species, regardless of species abundance. Plant species selection was positively correlated with species height in both vegetation communities (P<0.001). Despite this selective behaviour, animal stocking density played a key role in the selection of many species and this result suggests that animal management (*i.e.,* implementation of different stocking rates and densities) could be an important tool in modifying diet selection, promoting the consumption of particular plant species and thus managing the dynamics of plant communities in alpine environments.

Introduction

As a result of agro-pastoral activities, several semi-natural vegetation communities have established in the Alps during thousands of years (Sitzia and Trentanovi, 2011). After the Second World War, industrialization and urbanization brought agricultural abandonment in the mountain areas of Italy (Probo *et al*., 2013). As a consequence, the lack of grazing livestock led to decreased control of shrub and tree encroachment, reducing the area occupied by semi-natural grasslands, and to an increase in marginal land dominated by browse species (Tocco *et al.* 2013; Probo *et al*., 2014). In this socio-economic and environmental context, cattle rearing is often no longer profitable, but small ruminant rearing can still play a key role (Lombardi, 2005; Ascoli *et al.,* 2013). Indeed, the number of goats has recently increased in the north-western Italian Alps, where they are generally maintained on continuous extensive grazing systems in small farms, with less than 50 goats in more than 90% of cases (ISTAT, 2010).

Several studies on goat rearing have been conducted under different vegetation conditions, such as in African savannah (Sanon *et al.,* 2007), Atlantic heathlands (Celaya *et al.,* 2010; Osoro *et al.,* 2013), Mediterranean woodlands and rangelands (Rogosic *et al.*, 2006; Decandia *et al.,* 2008; Mancilla-Leyton *et al.,* 2013), and desert grasslands (Mellado *et al.,* 1991). These studies have mainly focused on feeding preferences of the goats, diet selection, feeding behaviour (*i.e.,* to determine if goats are grazers, browsers, or mixed feeders according to the definition of Hofmann and Stewart, 1972), and goat milk quality under different management systems. However, the feeding preferences, diet selection and feeding behaviour of goats have not undergone detailed investigation under extensive montane systems in the Alps. All of these feeding behaviours can be influenced by a complex variety of factors and their interactions, such as grazing regimes, stocking rate, forage accessibility, plant species abundance and abundance of neighbouring species, digestibility, and presence of toxic compounds (Mellado *et al.,* 1991; Baumont *et al.* 2000; Provenza *et al.,* 2003; Animut *et al.,* 2005; Papachristou *et al.,* 2005; Rogosic *et al.,* 2006; Decandia *et al.,* 2008; Celaya *et al.,* 2010; Mancilla-Leyton *et al.,* 2013). Some previous studies considered the selection of single plant species, carried out through direct observations of grazing animals (Perevolotsky *et al.,* 1998; Sanon *et al.,* 2007; Mancilla-Leyton *et al.,* 2013). However, this method cannot easily be applied to goats foraging on grasslands, as it is often difficult to distinguish the selection of single plant species within a mixed herbaceous layer. Moreover, only some studies considered stocking density (*sensu* Allen *et al.*, 2011) as an important variable affecting feeding preferences of livestock (Stuth *et al.,* 1987; Bailey and Brown, 2011; Hao *et al.,* 2013; Probo *et al.* 2014). To our knowledge, the effects of goat stocking density on feeding preferences have not been investigated in a montane setting, probably due to the difficulty of its precise assessment without the use of modern animal tracking systems (*e.g.,* GPS collars).

Our study aimed to assess goat feeding preferences by integrating vegetation surveys with animal GPS tracking under two contrasting alpine vegetation communities: a semi-natural grassland (SG) and a grazable forestland (GF). Specific objectives were: i) to assess single plant species selection; ii) to examine the influence of stocking density and plant species abundance on plant species selection; and iii) to examine the diet selection and the feeding behaviour of grazing goats.

Corresponding author: Dr. Gabriele Iussig, Dipartimento di Scienze Agrarie, Forestali e Alimentari, Università di Torino, Largo Paolo Braccini 2, 10095 Grugliasco (TO), Italy.
Tel. +39.011.6708929 - Fax: +39.011.2368791.
E-mail: gabriele.iussig@unito.it

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Materials and methods

Study area

The study was conducted at Oasi Zegna, located in the Piedmont Region of north-west Italy (latitude 45°40' N, longitude 8°09' E), within the boundaries of the Valle Sessera Site of Community Interest (SCI IT11300002). The study area is located within the mountain belt between 1250 and 1350 m asl and it is characterized by a sub-oceanic climate with an annual average air temperature of 7.2°C and an average precipitation of 1951 mm (Biancotti *et al*., 1998).

The dairy goat farm selected for the study held a flock of 14 lactating "Camosciata delle Alpi" goats reared under an extensive grazing system on grasslands and grazable forestlands. Semi-natural grasslands, belonging to *Nardo-Agrostion tenuis* Sillinger 1933 alliance, were characterized by a mix of grasses (*e.g., Festuca nigrescens* (Lam. non Gaudin)*, Agrostis tenuis* (Sibth.)) and forbs (*e.g., Potentilla erecta* (L.) Rauschel, *Achillea millefolium* L., and *Trifolium repens* L.). The grazable forestlands (*sensu* Allen *et al*., 2011), belonging to *Tilio platyphylli-Acerion pseudoplatani* Klika 1955 alliance, spread over most of the farm area and were composed of two main layers: a woody layer (dominated by *Sorbus aucuparia* L., *Sorbus aria* (L.) Crantz*, Salix caprea* L., *Rhododendron ferrugineum* L.*, Rubus hirtus* (W. et K.)*,* and *Rubus idaeus* L.), and an herbaceous layer (dominated by the grass *Calamagrostis arundinacea* (L.) Roth.).

Two different enclosures delimited with electric fences, one in a semi-natural grassland (SG) and another in a grazable forestland (GF), were arranged in similar topographic conditions (mean slope: 26°; mean exposition: 315° N), and with an average area of 0.7 and 0.9 ha, respectively. Goats were allowed to feed in the SG and GF enclosures for five (26 to 30 June) and six (23 to 28 July) days, respectively, to have the same average stocking rate of 0.26 goats ha^{-1} $year^{-1}$. This stocking rate was applied to i) simulate the conditions of continuous extensive grazing system widespread on Western Italian Alps, and ii) encourage selective grazing at low stocking density (Allen *et al*., 2011), so with high forage-to-animal ratio. The goats were milked indoors twice a day. At each milking, the goats were supplemented with 200 g $head^{-1}$ of a commercial concentrate. Goats were allowed to forage during the milking interval (*i.e.* from 7:00 AM to 6:00 PM) and were housed during night-time in a stable. Goats entered and exited each enclosure from a unique location during the study period. Both the enclosures and the stable were equipped to provide fresh water *ad libitum*.

Vegetation and plant species selection surveys

A dataset of 45 sampling points, placed at least 10-m apart from each other, was randomly-distributed on the map of each enclosure using the Random points plugin of QGIS (QGIS rel. 2.0.1, 2013). Their positions were identified in the field by a GPS device with an average accuracy of 2 m. At each point the botanical composition was assessed before goats were allowed into the enclosure and the selection of each plant species was evaluated after the exploitation. Botanical surveys were performed using the vertical point-quadrat method (Daget and Poissonet, 1971) along 5 m linear vegetation transects, with the centres matched to the random points (*i.e.*, 45 vegetation surveys for each enclosure). Along each transect, at every 10 cm interval, plant species touching a steel needle were identified and recorded (*i.e.*, 50 measurements of vegetation per transect). To overcome the underestimation of occasional species, which are often missed with the vertical point-quadrat method, all the species within a 2 x 5 m area (a vegetation plot) centered on the transect were recorded (Figure 1). Each species was classified according to the following functional groups (Allen *et al*., 2011): graminoid species, browse species, forbs, and ferns. For each plant species recorded in the vegetation transects the species frequency (SF_i) of occurrence, which is an estimate of species canopy cover, was calculated (Gallet and Roze, 2001; Lonati *et al*., 2009). A minimum value of 0.5 for SF was assigned to all occasional species, *i.e.*, to the species not recorded along the transects but within the vegetation plot (Kohler *et al.*, 2004). Species Relative Abundance (SRA_i) was calculated and used to detect the proportion of different species, according to the equation of Daget and Poissonet (1971):

$$SRA_i = \frac{SF_i}{\sum_{i=1}^{n} SF_i} * 100$$

The mean SRA was calculated for each plant species in each enclosure. To better investigate goat feeding behaviour, SRA by functional group was also calculated within each enclosure. Moreover, the average height of each species was obtained using Aeschimann *et al*. (2004). To assess plant species selection by goats, we modified the method proposed by Nagaike (2012) by fitting it to the point quadrat method. Five consecutive 1 m^2 squares were laid out on both sides of each 5 m vegetation transect and all species below 1.80 m of height (*i.e.*, to the level with the highest

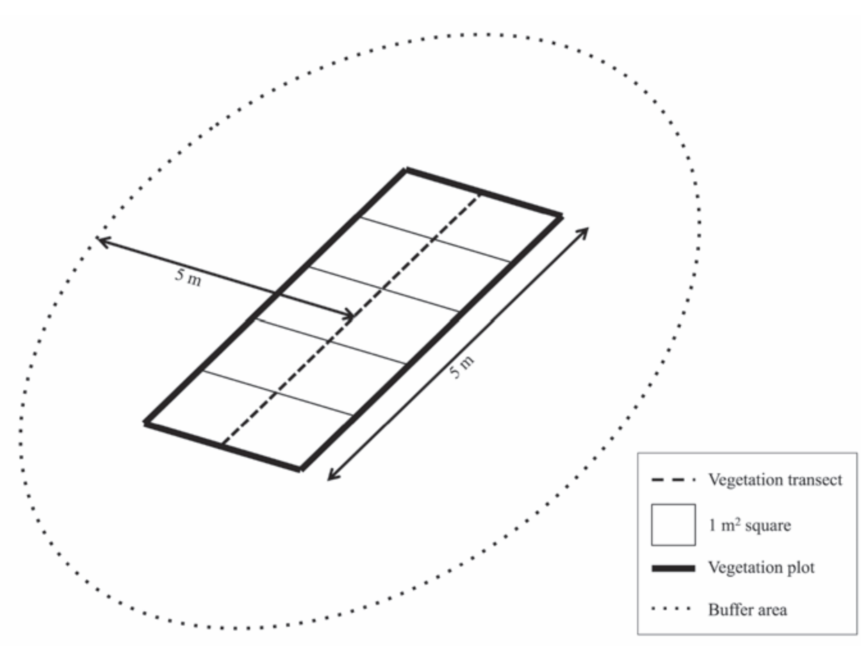

Figure 1. Scheme of the vegetation surveys carried out: vegetation transect, vegetation plot and 5 m buffer area around the sampling point.

browsing signs by goats) were recorded within each square (Figure 1). An intake value (I), ranging from 0 to 4, was visually estimated for each plant species occurring in every 1 m^2 square depending on its percent consumption at the end of feeding by goats: 0 (estimated consumption less than 20%), 1 (estimated consumption between 20 to 40%), 2 (estimated consumption between 40 to 60%), 3 (estimated consumption between 60 to 80%), and 4 (estimated consumption more than 80%). To estimate the percent consumption precisely, we calibrated the method for each plant species in neighbouring non-grazed vegetation outside each enclosure according to Hejcman *et al.* (2008). The most selected plant parts (flowers, stems, leaves, fruits, buds, sprouts), *i.e.*, parts grazed in more than 50% of the individual plants grazed, were noted for each species within each enclosure.

The consumption ratio (CR) was then calculated for each plant species in each vegetation plot using the following equation:

$$CR_i = \frac{\frac{1}{n}\sum_{j=1}^{n}(I_{ij})}{4} * 100(\%)$$

where CR_i is the consumption ratio for the plant species i, I_{ij} is the species estimated intake value for the species i in the square j, and n is the number of 1 m^2 squares where the species i was present. The CR represents the level of selection of each plant species within each vegetation plot and it ranges from 0% (ungrazed) to 100% (totally grazed). A mean CR was calculated for each plant species for each enclosure.

Species relative abundance (SRA) and CR were considered the best estimators of plant species biomass and selection by goats, respectively. The average percentage species intake (SI) was calculated for each species in each enclosure using the following equation:

$$SI_i = \frac{\frac{1}{k}\sum_{j=1}^{k}(CR_{ij} * SRA_{ij})}{\sum_{i=1}^{m}\left[\frac{1}{k}\sum_{j=1}^{k}(CR_{ij} * SRA_{ij})\right]} * 100(\%)$$

where SI_i is the average percentage intake of species i in the k vegetation plots where the species was recorded, SRA_{ij} is the species relative abundance of species i in the vegetation plot j, CR_{ij} is the consumption ratio of species i in the plot j, and m is the total number of species within the enclosure. The numerator represents the average intake of species i and the denominator represents the sum of the average intake of all the species within each enclosure. The goat diet selection within each enclosure was estimated from the SI of all the species recorded. Following criteria suggested by Hofmann and Stewart (1972), goat feeding behaviour was classified in terms of the percentage of herbaceous and browse species in the diet composition within each enclosure. These authors considered goats as grazers when the content of browse species in the diet is lower than 25%, mixed feeders when the content of browse species in the diet ranges from 25% to 75% and browsers when the content of browse species in the diet is higher than 75%.

Goat GPS tracking

Ten goats were randomly selected within the flock. Each goat was tracked using a GPS datalogger collar every day of the foraging period and during the milking interval (the devices were turned on at the morning milking and turned off during the evening milking). The GPS-position of each animal was recorded every 10 s, with an average accuracy of 2.5 m. The number of GPS fixes of the flock in the 5 m buffer area around the centre of each vegetation transect (i.e. twice the average datalogger accuracy) was used to assess the stocking density within the SG and GF enclosures (Figure 1). The distance between each point and the location where goats entered each enclosure was calculated to assess goat spatial distribution and its relation with the entrance location. All geographical analyses were performed using QGIS ver. 2.0.1 (2013).

Statistical analyses

The relationships between the mean CR of each plant species and the mean SRA and height of the same species within each enclosure was tested using Spearman's rank correlation. The experimental unit for the CR was the vegetation plot, and the experimental unit for the SRA was the vegetation transect. These analyses were performed not considering the species recorded in less than ten out of the 45 vegetation plots for which robust statistics could not be computed. To assess differences among the CR of functional groups in each enclosure, a non-parametric Kruskal-Wallis ANOVA was performed, excluding the groups with less than two species.

A linear regression between animal stocking density (*i.e.*, the number of GPS fixes within the 5 m buffer areas over the whole monitoring period) and the distance from the locations goats entered each enclosure was performed. The number of fixes was $\log_{10}$ transformed prior to analysis to achieve a normal distribution of residuals. The experimental unit for stocking density was the buffer area.

The selection of each plant species by goats was modelled by fitting Generalized Linear Models (GLMs) to CR data within each enclosure. A stepwise procedure based on the Akaike Information Criterion was implemented using the step-AIC function (R MASS package) (Venables and Ripley, 2002). Percent deviance explained (D^2) was used as a measure of goodness-of-fit. Percent deviance explained was calculated as the ratio of the difference between null deviance and residual deviance, and null deviance, where null deviance is the deviance of an intercept-only GLM, and residual deviance is the deviance that remains unexplained after model fit. The GLM analyses were performed for the ten most abundant species in each enclosure to evaluate the most important species in the total aboveground phytomass. The dependent variable was ranked into 100 classes (corresponding to a 1% interval), and a negative binomial distribution was specified, as it was a count overdispersed variable (over-dispersion was tested with the qcc R package (Scrucca, 2004)). The animal stocking density, the SRA of the subject species and the SRA of the other most abundant species within each enclosure were used as explanatory variables in the GLMs. A correlation analysis of explanatory variables was initially used to examine whether any predictors were highly correlated ($r>|0.8|$) and thus to avoid collinearity. Predictors were standardised (Z-scores) to allow for analysis of effect size by scrutinising model parameters (β coefficients). All analyses were carried out using R 2.15.2 (R Development Core Team, 2005).

Results and discussion

Vegetation and plant species selection by goats

A total of 84 and 67 plant species were identified in SG and GF enclosures, respectively (Table 1 and Table 2). The ten most abundant species accounted for 83.9% and 86.1% of total SRA in the SG and GF enclosure, respectively. The SG enclosure was dominated by a homogeneous herbaceous layer (average SRA 98.7%) characterized by graminoid species (79.3%), forbs (19.1%) and ferns (0.3%), while the woody layer (browse species) accounted only for 1.3% (Table 1). Conversely, in the GF enclosure the vertical structure of vegetation was more heterogeneous and stratified into two main layers: i) an herbaceous layer (average SRA 60.8%) composed by graminoid species (46.6%), ferns (8.1%), and forbs (6.1%), and ii) a woody layer, dominated by browse species (39.2%) (Table 2).

The average CR of the most frequent species, *i.e.*, 37 and 22 species within the SG and GF enclosures respectively (Figure 2 and Figure 3), was positively correlated with species height in both the enclosures (r_S=0.62 and P<0.001 for SG and r_S=0.83 and P<0.001 for GF; Table 1 and Table 2). High CR values for the tallest species (*e.g. F. nigrescens, Poa pratensis* L., *Phyteuma betonicifolium* Vill., *A. millefolium* in the SG enclosure and *S. aria*, *S.*

Table 1. Botanical composition, functional groups, species occurrence, species relative abundance, percentage consumption ratio ± SE, and average species height in the semi-natural grassland enclosure. Floristic nomenclature follows Pignatti (1982).

Species	Family	Functional group	Species occurrence°	SRA, %	CR, % ±SE	Species height,# cm
Festuca nigrescens	*Poaceae*	Gr	45	26.5	26±3.3	55.0
Agrostis tenuis	*Poaceae*	Gr	45	23.0	25±3.2	40.0
Phleum alpinum	*Poaceae*	Gr	45	11.9	21±2.3	30.0
Nardus stricta	*Poaceae*	Gr	35	6.1	0±0.2	20.0
Avenella flexuosa	*Poaceae*	Gr	41	5.3	13±2.8	40.0
Achillea millefolium	*Asteraceae*	Fo	29	3.1	23±4.2	45.0
Trifolium repens	*Fabaceae*	Fo	31	2.6	7±2.4	25.0
Anthoxanthum alpinum	*Poaceae*	Gr	38	1.9	4±1.2	25.0
Potentilla erecta	*Rosaceae*	Fo	43	1.9	0±0.2	22.5
Ranunculus montanus	*Ranunculaceae*	Fo	45	1.7	10±1.7	22.5
Poa annua	*Poaceae*	Gr	12	1.4	38±8.1	15.0
Veronica officinalis	*Plantaginaceae*	Fo	38	1.3	1±0.5	20.0
Poa pratensis	*Poaceae*	Gr	17	1.1	27±5.7	50.0
Vaccinium myrtillus	*Ericaceae*	Br	26	1.0	5±1.1	30.0
Veronica chamaedrys	*Plantaginaceae*	Fo	31	0.9	1±0.3	20.0
Carex leporina	*Cyperaceae*	Gr	23	0.7	8±3.7	35.0
Veronica serpyllifolia	*Plantaginaceae*	Fo	32	0.7	0±0.4	15.0
Cerastium holosteoides	*Caryophyllaceae*	Fo	37	0.6	1±0.8	30.0
Potentilla aurea	*Rosaceae*	Fo	21	0.6	0±0.4	12.5
Rumex acetosella	*Polygonaceae*	Fo	29	0.5	10±2.9	20.0
Alchemilla vulgaris	*Rosaceae*	Fo	30	0.5	1±0.6	30.0
Ranunculus acris	*Ranunculaceae*	Fo	15	0.5	8±2.7	50.0
Lolium perenne	*Poaceae*	Gr	9	0.4	51±11.2	45.0
Chaerophyllum hirsutum	*Apiaceae*	Fo	26	0.4	17±5.4	65.0
Luzula campestris	*Juncaceae*	Gr	24	0.4	5±4.3	15.0
Phyteuma betonicifolium	*Campanulaceae*	Fo	18	0.3	37±8.5	47.5
Gnaphalium sylvaticum	*Asteraceae*	Fo	29	0.3	4±2.6	32.5
Maianthemum bifolium	*Asparagaceae*	Fo	19	0.3	1±1.3	12.5
Athyrium filix-foemina	*Athyriaceae*	Fe	20	0.3	20±6.0	75.0
Campanula scheuchzeri	*Campanulaceae*	Fo	23	0.3	1±0.5	24.0
Rumex acetosa	*Polygonaceae*	Fo	28	0.3	22±4.6	85.0
Carex pilulifera	*Cyperaceae*	Gr	14	0.3	4±2.4	20.0
Thymus gr. serpyllum	*Lamiaceae*	Fo	14	0.3	1±0.6	6.0
Rubus idaeus	*Rosaceae*	Br	20	0.2	14±5.3	140.0
Astrantia minor	*Apiaceae*	Fo	15	0.2	0±0.4	30.0
Plantago major	*Plantaginaceae*	Fo	16	0.2	9±3.7	20.0
Anemone nemorosa	*Ranunculaceae*	Fo	17	0.2	0±0.0	16.0
Lotus alpinus	*Fabaceae*	Fo	8	0.1	6±4.1	7.5
Prunella vulgaris	*Lamiaceae*	Fo	10	0.1	3±2.5	12.5
Leontodon autumnalis	*Asteraceae*	Fo	9	0.1	2±1.4	29.0
Trifolium pratense	*Fabaceae*	Fo	9	0.1	13±5.9	25.0
Carex brizoides	*Cyperaceae*	Gr	6	0.1	5±2.4	40.0
Lathyrus montanus	*Fabaceae*	Fo	3	0.1	0±0.0	22.5
Polygala chamaebuxus	*Polygalaceae*	Fo	7	0.1	7±7.1	12.5
Viola riviniana	*Violaceae*	Fo	12	0.1	0±0.0	15.0
Others§	-	-	-	1.0	-	

SRA, species relative abundance; CR, consumption ratio; Gr, graminoid species; Fo, forbs; Br, browses; Fe, ferns. °Number of vegetation plots wherein each species was recorded over 45 vegetation plots. #Species heights are calculated averaging the minimum and maximum values of height according to Aeschimann *et al.* (2004). §Species with SRA <0.1: *Leontodon helveticus* (*Asteraceae*), *Carex pallescens* (*Cyperaceae*), *Crocus albiflorus (Iridaceae), Sorbus aucuparia* (*Rosaceae*), *Silene vulgaris (Caryophyllaceae), Leonthodon hispidus (Asteraceae), Poa alpina (Poaceae), Hieracium pilosella* (*Asteraceae*), *Homogyne alpina* (*Asteraceae*), *Trisetum flavescens (Poaceae), Cirsium palustre (Asteraceae), Urtica dioica* (*Urticaceae*), *Galeopsis tetrahit* (*Lamiaceae*), *Taraxacum officinale (Asteraceae), Bromus erectus* (*Poaceae*), *Dactylis glomerata (Poaceae), Stellaria graminea* (*Caryophyllaceae*), *Veratrum album (Liliaceae), Rumex obtusifolius* (*Polygonaceae*), *Hieracium sylvaticum (Asteraceae), Cruciata glabra* (*Rubiaceae*), *Gentiana kochiana (Gentianaceae), Astrantia major (Apiaceae), Stachys pradica (Lamiaceae), Hieracium auricula (Asteraceae), Galium anisophyllum (Rubiaceae), Sagina procumbens* (*Caryophyllaceae*), *Oxalis acetosella (Oxalidaceae), Luzula multiflora (Juncaceae), Leucanthemum vulgare* (*Asteraceae*), *Silene nutans (Caryophyllaceae), Arnica montana (Asteraceae), Festuca varia (Poaceae), Vaccinium vitis-idaea (Ericaceae), Ajuga reptans* (*Lamiaceae*), *Juncus effusus* (*Juncaceae*), *Cardaminopsis halleri* (*Brassicaceae*), *Cerastium arvense (Caryophyllaceae), Danthonia decumbens (Poaceae)*.

aucuparia, S. caprea, Veratrum album L. in the GF enclosure) were probably due to the preference by goats to feed at eye-level (Lu, 1988) and, in general, forage vegetation from the top downwards (Del Pozo and Osoro, 1997; Lamy *et al*., 2012). Conversely, short species (e.g. *P. erecta, Astrantia minor* L., *Maianthemum bifolium* (L.) Schmidt) were partially or totally avoided, probably as a consequence of the preference for taller plant species and also by the need of goats to reduce the risk of infection by parasite eggs found on plants closer to the soil (Lu, 1988). For these reasons, *T. repens* was probably avoided by the goats even though it is considered higher quality forage than many other pasture species (Bovolenta *et al.*, 2008; Tava *et al*., 2011). Similar results were achieved by Clark *et al.* 1982 and Grant *et al.* 1984 who observed that goats tend to avoid or do not preferentially select clover, at least not as much as sheep. However, some contradictory results emerged from different research (Nicol and Collins 1990; Penning *et al.* 1997).

The average CR of the most frequent species

Table 2. Botanical composition, functional groups, species occurrence, species relative abundance, percentage consumption ratio ± SE, and average species height in the grazable forestland enclosure. Floristic nomenclature follows Pignatti (1982).

Species	Family	Functional group	Species occurrence°	SRA, %	CR, % ±SE	Species height,[#] cm
Calamagrostis arundinacea	*Poaceae*	Gr	45	35.1	24±2.8	90.0
Rhododendron ferrugineum	*Ericaceae*	Br	44	16.8	0±0.2	75.0
Vaccinium myrtillus	*Ericaceae*	Br	44	11.6	19±2.4	30.0
Avenella flexuosa	*Poaceae*	Gr	38	6.6	3±1.0	40.0
Phegopteris polypodioides	*Thelypteridaceae*	Fe	40	5.1	3±0.7	20.0
Rubus hirtus	*Rosaceae*	Br	33	3.9	26±3.9	140.0
Luzula nivea	*Juncaceae*	Gr	29	2.4	27±4.4	65.0
Rubus idaeus	*Rosaceae*	Br	28	1.7	20±3.7	140.0
Sorbus aucuparia	*Rosaceae*	Br	36	1.6	55±5.1	180.0
Veratrum album	*Liliaceae*	Fo	31	1.5	71±4.6	100.0
Calluna vulgaris	*Ericaceae*	Br	7	1.1	2±1.2	50.0
Potentilla erecta	*Rosaceae*	Fo	21	1.0	3±1.2	22.5
Lycopodium clavatum	*Lycopodiaceae*	Fe	10	0.9	0±0.0	10.0
Salix caprea	*Salicaceae*	Br	21	0.9	44±5.5	180.0
Nardus stricta	*Poaceae*	Gr	9	0.8	1±0.5	20.0
Sorbus aria	*Rosaceae*	Br	18	0.7	62±7.2	180.0
Carex pilulifera	*Cyperaceae*	Gr	12	0.7	3±1.4	20.0
Polygala chamaebuxus	*Polygalaceae*	Fo	12	0.7	0±0.2	12.5
Athyrium filix-foemina	*Athyriaceae*	Fe	23	0.7	12±3.0	75.0
Thelypteris limbosperma	*Thelypteridaceae*	Fe	13	0.6	11±3.2	65.0
Athyrium distentifolium	*Athyriaceae*	Fe	9	0.6	21±6.0	100.0
Festuca scabriculmis	*Poaceae*	Gr	3	0.6	25±10.8	40.0
Senecio fuchsii	*Asteraceae*	Fo	11	0.5	83±9.0	105.0
Vaccinium vitis-idaea	*Ericaceae*	Br	10	0.5	0±0.0	100.0
Homogyne alpina	*Asteraceae*	Fo	22	0.5	0±0.2	20.0
Viola riviniana	*Violaceae*	Fo	7	0.4	0±0.0	15.0
Euphorbia carniolica	*Euphorbiaceae*	Fo	26	0.3	4±2.0	40.0
Maianthemum bifolium	*Asparagaceae*	Fo	19	0.3	1±1.3	12.5
Fagus sylvatica	*Fagaceae*	Br	10	0.2	13±5.9	180.0
Astrantia minor	*Apiaceae*	Fo	14	0.2	4±2.0	30.0
Dryopteris filix-mas	*Dryopteridaceae*	Fe	13	0.2	10±4.1	75.0
Betula pendula	*Betulaceae*	Br	6	0.2	33±10.7	180.0
Danthonia decumbens	*Poaceae*	Gr	6	0.2	16±11.2	25.0
Agrostis tenuis	*Poaceae*	Gr	9	0.1	1±1.1	40
Gentiana purpurea	*Gentianaceae*	Fo	6	0.1	21±7.7	40.0
Others[§]	-	-	-	0.7	-	

SRA, Species relative abundance; CR, consuption ratio; Gr, graminoid species; Br, browses; Fe, ferns; Fo, forbs. °Number of vegetation plots wherein each species was recorded over 45 vegetation plots. [#]Species heights are calculated averaging the minimum and maximum values of height according to Aeschimann *et al.* (2004). [§]Species with SRA <0.1: *Festuca tenuifolia* (*Poaceae*), *Gentiana kochiana (Gentianaceae), Carex pallescens* (*Cyperaceae*), *Oxalis acetosella (Oxalidaceae), Rosa pendulina (Rosaceae), Prenanthes purpurea (Asteraceae), Saxifraga cuneifolia* (*Saxifragaceae*), *Chaerophyllum hirsutum* (*Apiaceae*), *Festuca nigrescens (Paoceae), Polygonatum verticillatum (Asparagaceae), Carex sempervirens (Cyperaceae), Pyrola rotundifolia* (*Ericaceae*), *Phyteuma scheuchzeri* (*Campanulaceae*), *Alnus viridis (Betulaceae), Anthoxantum alpinum (Poaceae), Scrophularia nodosa (Scrophulariaceae), Anemone nemorosa (Ranunculaceae), Dryopteris dilatata* (*Dryopteridaceae*), *Pteridium aquilinum (Hypolepidaceae), Paris quadriflora (Liliaceae), Lathyrus montanus (Fabaceae), Hieracium sylvaticum* (*Asteraceae*), *Epilobium angustifolium (Onagraceae), Veronica officinalis (Plantaginaceae), Blechnum spicant* (*Blechnaceae*), *Arnica montana (Asteraceae), Daphne mezereum* (*Thymelaeaceae*), *Gentiana asclepiadea* (*Gentianaceae*), *Acer pseudoplatanus (Aceraceae), Aruncus dioicus (Rosaceae), Genista germanica* (*Fabaceae*), *Molinia arundinacea* (*Poaceae*).

was positively correlated with their average SRA only within the SG enclosure (r_S=0.32 and P=0.050), and not in the GF enclosure (P>0.05). This result suggests that the goats were less selective within the homogeneous herbaceous environment of the SG enclosure because they tended to select species proportionally to their abundance. In contrast, in the heterogeneous and stratified habitat found in the GF enclosure the goats showed a more pronounced preference for some species, which reached the highest CR values regardless of their abundance (Figure 3). The selection by goats seemed to be more species-dependent rather than functional group-dependent. Indeed, no difference in the selection of different functional groups was detected within both enclosures (Kruskall-Wallis test; P>0.05) as within each group both highly preferred and avoided species occurred (Figure 2 and Figure 3). As an example, browse species within the GF enclosure were on average markedly selected except for *R. ferrugineum*, which was totally avoided even though it was largely widespread over the whole area. Goats may avoid *R. ferrugineum* because of its high content of plant secondary metabolites which reduce its digestibility (Humphreys *et al.*, 1983; Eo and Kwon, 2009). However, the level of toxins in the plant material did not appear to have a simple relationship with selection by goats. For example, forbs within the same enclosure were generally less selected or avoided except *V. album*, a species well known to have high levels of toxic compounds (Schaffner *et al.,* 2001; Kleijn and Steinger, 2002; Panter *et al.,* 2013), which showed the highest CR value (*i.e.*, 71%). Similarly, other potentially toxic species, like ferns (*Athyrium filix-foemina* (L.) Roth, *Dryopteris filix-mas* (L.) Schott, *Thelypteris limbosperma* (All.) H. P. Fuchs) (Fenwick, 1990; Pakeman *et al.,* 2002), were partly selected by goats in both the enclosures (Figure 2 and Figure 3). The selection and ingestion of poisonous plant species by goats is still barely investigated, although many authors have suggested that goats are better suited to tolerate and detoxify natural toxins when compared to other ruminants (Silanikove *et al.,* 1996; Provenza *et al.,* 2003; Papachristou *et al.*, 2005; Hoste *et al.,* 2010). Therefore the observed feeding selection by goats might be considered to result from a positive process to obtain a more balanced intake of nutrients rather than resulting from a negative process of avoiding certain species containing toxins (Provenza *et al.*, 2003).

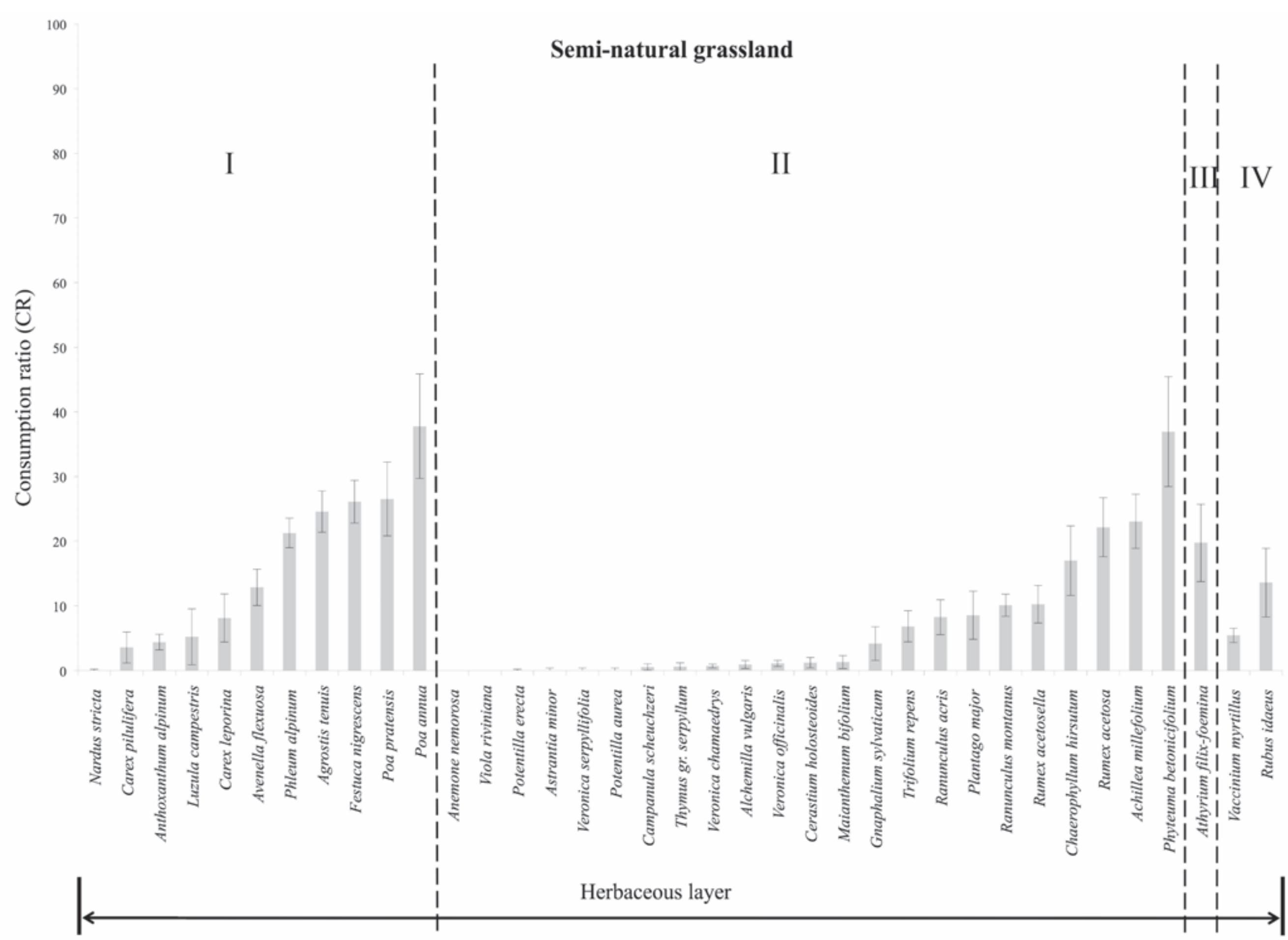

Figure 2. Consumption ratio (%) ± SE of the most frequent species occurred in the semi-natural grassland (SG) enclosure. Species are grouped according to the following functional groups (Allen *et al.*, 2011): (I) graminoid species, (II) forbs, (III) ferns, and (IV) browse species.

Influence of stocking density and vegetation variables on plant species selection by goats

A total of 123,451 (along the five grazing days) and 191,668 (along the six grazing days) GPS fixes was recorded in the SG and GF enclosures, respectively. As expected, stocking density within both enclosures was heterogeneous, due to the low stocking rate implemented to foster selective behaviour, and it was negatively related to the distance from the location goats entered the enclosure (P<0.001) (Figure 4).

Based on the results of the correlation analysis, none of the predictors was excluded from the GLM analyses for collinearity. As expected, no significant predictors were detected for the CR value of the avoided species, *i.e.*, *Nardus stricta* L. and *P. erecta* in the SG enclosure and *R. ferrugineum* in the GF enclosure (Table 3 and Table 4). Stocking density was an important predictor (P<0.1) for most of the other species within both enclosures, showing a positive relation with the CR values. Moreover, the comparison among the - values of the significant predictors confirmed the importance of stocking density in plant species selection, as these values were often among the highest β-values. This finding suggests that varying livestock stocking density might condition the consumption of many plant species.

Single species selection was more affected by the SRA of the other most abundant species rather than the SRA of the same species (Table 3 and Table 4). When the SRA significantly influenced the selection of the same species, a

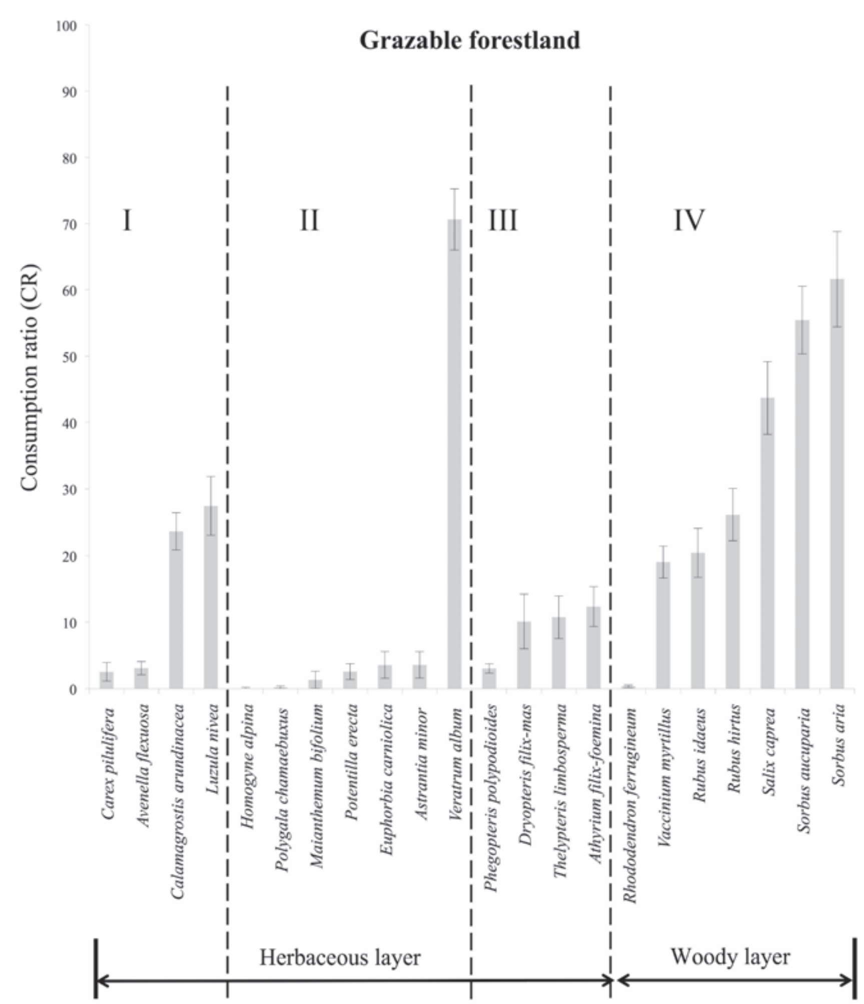

Figure 3. Consumption ratio (%)± SE of the most frequent species occurred in the grazable forestland (GF) enclosure. Species are grouped according to the following functional groups (Allen *et al.*, 2011): (I) graminoid species, (II) forbs, (III) ferns, and (IV) browse species.

Table 3. Coefficients for stocking density and species relative abundance affecting the consumption ratio of the ten most abundant species in the semi-natural grassland enclosure in stepwise GLM models. Percent deviance explained (D^2) was used as a measure of goodness-of-fit.

Species (consumption ratio)	Stocking density	SRA *N. stricta*	SRA *P. erecta*	SRA *A. alpinum*	SRA *T. repens*	SRA *R. montanum*	SRA *A. flexuosa*	SRA *P. alpinum*	SRA *A. millefolium*	SRA *A. tenuis*	SRA *F. nigrescens*	D^2
Nardus stricta (0)												-
Potentilla erecta (0)												-
Anthoxanthum alpinum (4)	0.82**		-7.79**	1.59***				- 1.07*				77.26
Trifolium repens (7)	2.03***	-0.81**	-1.19***	-0.65***		-1.10***	-1.04**	- 0.96**			- 1.09**	44.69
Ranunculus montanus (10)		0.67*		0.56*			-0.86**					17.17
Avenella flexuosa (13)			-0.74**			-0.75**		- 0.96***		- 1.10 ***	- 0.53°	59.75
Phleum alpinum (21)	0.29**			0.19°			-0.33**	0.22°			- 0.32**	36.18
Achillea millefolium (23)	0.35**		-0.40°		0.71***		2.04***	- 0.30°	0.55**		0.34°	69.56
Agrostis tenuis (25)	0.29**	-0.34**		0.28**	0.25*						- 0.18°	50.11
Festuca nigrescens (26)	0.28*	-0.25°		0.23*	0.21°			- 0.21°				41.28

SRA, species relative abundance. °P<0.10; *P<0.05; **P<0.01; ***P<0.001.

positive relation was observed. Instead, the relations among the CR and the SRA of the other most abundant species highlighted a more complex situation. As an example, in the SG enclosure the SRA of the most selected species (*e.g*., *F. nigrescens, A. tenuis* and *Phleum alpinum* L.) was mostly negatively related to the selection of the least selected species (*e.g*., *N. stricta*). This result indicated that goats tended to reduce the consumption of some species when other more palatable species were more abundant. In contrast, within the same enclosure, the increase in the SRA of *Anthoxanthum alpinum* Love et Love and *T. repens* seemed to foster the intake of other species. Concerning *A. alpinum*, probably this species was only a little selected by goats because of its high quantity of coumarin, an aromatic compound, within its tissues (Tava, 2001). Similarly, within the GF enclosure, the increase of the SRA of the most selected species (e.g. *V. album, S. aucuparia* and *C. arundinacea*) negatively affected the CR of the least selected species. In both the enclosures, most of the other β coefficients did not highlight any unequivocal influence on species selection. Nevertheless, some models showed a high percent deviance explained (*e.g*., *A. alpinum* and *A. millefolium*) and in general models appeared more informative in the SG than in the GF enclosure, accounting for 50% and 31% of deviance explained on average. The influence of stocking density and vegetation variables on species selection by goats appeared to be a very complex phenomenon and it was generally less predictable for grazable forestlands than for semi-natural grasslands. This result may be due to the influence of vegetation structure and composition on goat feeding behaviour, which could have some explanatory variables not easily ponderable and assessable with statistical models (e.g. palatability, individual feeding preference).

Goat diet selection and feeding behaviour

The type of food eaten by the goats in this study was highly variable. In the SG habitat 56 of the 84 plant species were consumed and in the GF habitat 47 of the 67 species were consumed. Selected plants belonged to all four functional groups (graminoids, forbs, ferns and browse species) and a range of plant parts, from flowers and fruits to stems and leaves, was consumed (Table 5). The most selected plant parts were flowers (19 species out of 22), stems (13) and leaves (13) in the SG enclosure, whereas in the GF enclosure they were leaves (25 out of 29), flowers (15) and stems (7). These results confirmed the great ability by goats to select different plant parts and species among those that they encounter, thanks to the shape of incisor arcades and the mobile lips (Lamy *et al.*, 2012; Rosenthal *et al.*, 2012). The average percentage species intake (SI) of the first ten species accounted for 94.56% and 90.57% of the total SI in the SG and the GF enclosure, respectively (Table 5). As reported by Papachristou *et al*. (2005), goats tend to select a high array of plant species under different environments, but most of their diet is generally composed by a few species. Within both enclosures the most selected species belonged to graminoids (SG: 88.15% of SI; GF: 51.33%), followed by forbs in the SG (10.99%) and browse species in the GF enclosure (38.08%), respectively. In particular, most of the graminoid flowers were grazed in the SG enclosure, probably due to their higher visibility, accessibility, and the lower energetic cost to forage the tallest part of the plants (Lamy *et al.*, 2012). In the GF enclosure goats tended to select browse species material, pos-

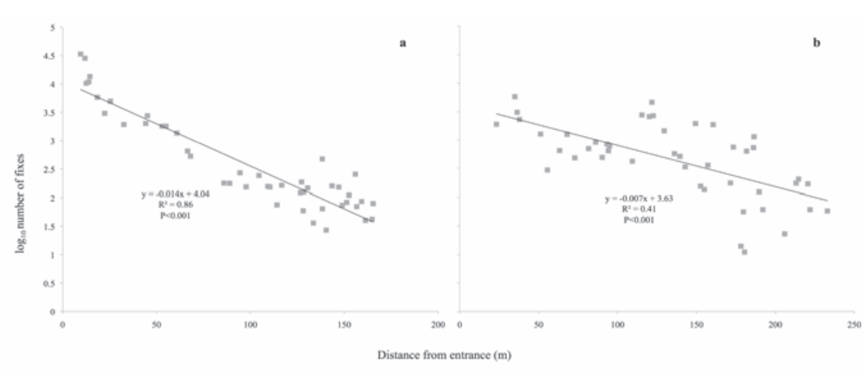

Figure 4. Linear regression between animal stocking density in the 5 m buffer sampling areas (n=45) and the distance from the location goats entered in the a) semi-natural grassland and b) grazable forestland enclosure.

Table 4. Coefficients for stocking density and species relative abundance affecting the consumption ratio of the ten most abundant species in the grazable forestland enclosure in stepwise GLM models. Percent deviance explained (D^2) was used as a measure of goodness-of-fit.

Species (consumption ratio)	Stocking density	SRA *R. ferrugineum*	SRA *A. flexuosa*	SRA *P. polypodioides*	SRA *V. myrtillus*	SRA *R. idaeus*	SRA *C. arundinacea*	SRA *R. hirtus*	SRA *L. nivea*	SRA *S. aucuparia*	SRA *V. album*	D^2
Rhododendron ferrugineum (0)												-
Avenella flexuosa (3)		-1.97***	0.72*		0.95*					-2.26°		57.03
Phegopteris polypodioides (3)	0.57*				-0.51°							19.33
Vaccinium myrtillus (19)		-0.35**	-0.42**		0.18°		-0.60***					29.85
Rubus idaeus (20)	0.35°										-0.47°	11.86
Calamagrostis arundinacea (24)	0.81***	-0.21°		-0.28*		-0.22°	0.23°	0.23*				46.91
Rubus hirtus (26)											-0.49**	10.11
Luzula nivea (27)	1.08***			-0.33°					0.79***	-0.45**	0.40**	56.66
Sorbus aucuparia (55)	0.31**		0.30**		0.65***			0.16°		0.33**		35.69
Veratrum album (71)	0.14*											10.58

SRA, species relative abundance. °P<0.10; *P<0.05; **P<0.01; ***P<0.001.

Table 5. Estimated species intake, functional groups, plant parts selected, species relative abundance, and percentage consumption ratio of the most selected species in the semi-natural grassland and the grazable forestland enclosures.

		SI, %	FG	Plant parts selected	SRA, %	CR, %
Semi-natural grassland						
	Festuca nigrescens	33.49	Gr	Fl, St, Le	26.5	26
	Agrostis tenuis	29.36	Gr	Fl, St, Le	23.0	25
	Phleum alpinum	12.07	Gr	Fl, St, Le	11.9	21
	Achillea millefolium	5.61	Fo	Fl, St, Le	3.1	23
	Avenella flexuosa	4.94	Gr	St, Le, Bu	5.3	13
	Poa annua	3.32	Gr	Fl, St, Le	1.4	38
	Poa pratensis	2.27	Gr	Fl, St, Le	1.1	27
	Trifolium repens	1.47	Fo	Fl	2.6	7
	Lolium perenne	1.20	Gr	Fl, St, Le	0.4	51
	Ranunculus montanus	0.82	Fo	Fl, Fr	1.7	10
	Chaerophyllum hirsutum	0.76	Fo	Fl, St	0.4	17
	Anthoxanthum alpinum	0.69	Gr	Fl	1.9	4
	Phyteuma betonicifolium	0.62	Fo	Fl, St, Le	0.3	37
	Carex leporina	0.48	Gr	Fl, St	0.7	8
	Vaccinium myrtillus	0.36	Br	Le, Sp	1.0	5
	Rumex acetosa	0.32	Fo	Fl, Le, Fr	0.3	22
	Rumex acetosella	0.28	Fo	Fl, St	0.5	10
	Ranunculus acris	0.26	Fo	Fl	0.5	8
	Rubus idaeus	0.26	Br	Fl, St, Le, Sp	0.2	14
	Athyrium filix-foemina	0.23	Fe	Le	0.3	20
	Veronica officinalis	0.11	Fo	Fl, Le	1.3	1
	Veratrum album	0.11	Fo	Fl	< 0.1	92
	Others	0.97			-	-
Grazable forestland						
	Calamagrostis arundinacea	42.78	Gr	Fl, St, Le	35.1	24
	Vaccinium myrtillus	15.71	Br	Le, Sp	11.6	19
	Sorbus aucuparia	5.93	Br	Le	1.6	55
	Rubus hirtus	5.90	Br	Fl, Le, Fr	3.9	26
	Veratrum album	4.50	Fo	Fl, Le, Fr	1.5	71
	Luzula nivea	4.12	Gr	Fl, St, Le	2.4	27
	Sorbus aria	3.40	Br	Le	0.7	62
	Rubus idaeus	3.08	Br	Fl, Le, Fr	1.7	20
	Salix caprea	2.61	Br	Le	0.9	44
	Avenella flexuosa	2.55	Gr	Fl, St, Le	6.6	3
	Senecio fuchsii	2.25	Fo	Fl, Le	0.5	83
	Festuca scabriculmis	1.00	Gr	Fl, Le	0.6	25
	Phegopteris polypodioides	0.94	Fe	Le	5.1	3
	Athyrium distentifolium	0.74	Fe	Le	0.6	21
	Betula pendula	0.49	Fe	Le	0.2	33
	Athyrium filix-foemina	0.49	Br	Le, Sp	0.7	12
	Thelypteris limbosperma	0.45	Fe	Le	0.6	11
	Rhododendron ferrugineum	0.43	Br	Le, Sp	16.8	0
	Potentilla erecta	0.42	Fo	Fl, St, Le, Fr	1.0	3
	Danthonia decumbens	0.38	Gr	Fl, St, Le	0.2	16
	Fagus sylvatica	0.29	Br	Le, Bu	0.2	13
	Festuca nigrescens	0.17	Br	Le, Sp	< 0.1	25
	Calluna vulgaris	0.17	Gr	Fl, Le	1.1	2
	Dryopteris filix-mas	0.14	Fe	Le	0.2	10
	Carex pilulifera	0.12	Gr	Fl, St	0.7	3
	Nardus stricta	0.12	Gr	Fl	0.8	1
	Prenanthes purpurea	0.11	Fo	Fl, St, Le	< 0.1	25
	Gentiana purpurea	0.10	Fo	Fl, Fr	0.1	21
	Astrantia minor	0.10	Fo	Le	0.2	4
	Others	0.51			-	-

SI, species intake; FG, functional groups; SRA, species relative abundance; CR, consumption ratio; Gr, graminoid species; Fo, forbs; Br, browses; Fe, ferns; Fl, flowers; St, stems; Le, leaves; Fr, fruits; Bu, buds; Sp, sprouts.

sibly because it generally provides a relatively constant source of nutrients throughout the summer season compared to some herbaceous species (Papachristou *et al.*, 2005). Furthermore, feeding choices must take into account that, thanks to the taste receptors located in the mouth and the saliva present in the oral cavity, goats are highly able to feel quality changes (Lamy *et al.*, 2012).

On the whole, these results confirm that goats can modify their diet and preferences depending on the habitat in which they are foraging (Animut *et al.,* 2005; Lamy *et al.,* 2012). According to the criteria of Hofmann and Stewart (1972) and Shipley (1999), the goats in this study would be considered as mixed feeders in GF because the content of browse species in the diet was between 25% and 75%.

Conclusions

This study confirmed the ability of goats to adapt their feeding preferences to the plant community in which they forage in alpine montane environments. Within the studied vegetation communities the feeding preference by goats was more species-dependent rather than functional group-dependent. Goats appeared to be less selective within a homogeneous herbaceous grassland, because they tended to select plant species proportionally to their abundance. On the contrary, in a heterogeneous and stratified grazable forestland they showed a more pronounced preference for most of the browse species, regardless of species abundance. Despite this selective behaviour, stocking density also played a key role in the selection of many species and suggests that animal management (*i.e.*, implementation of different stocking rates and densities) could be an important tool in modifying diet selection, promoting the consumption of particular plant species and thus managing the dynamics of plant communities in alpine environments.

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