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Implementation of a rotational grazing system with large paddocks changes the distribution of grazing cattle in the south-western Italian Alps

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Continuous grazing systems (CGS) are still widely used for managing cattle herds in the south-western Alps. Recently, Pastoral Plans have been used as a policy tool to improve grazing management. Rotational grazing systems (RGS) with large paddocks (i.e. ~100 ha on average) and stocking rate adjustments based on recommended levels calculated from vegetation surveys have been implemented through Pastoral Plans to improve the uniformity of grazing. A case study was conducted to compare grazing distribution patterns of beef cows during the summer under CGS and RGS on sub-alpine and alpine pastures within Val Troncea Natural Park in the south-western Alps of Italy. Cows were tracked with global positioning system collars at 15-min intervals under both CGS and RGS. Cattle distribution patterns were aggregated in both grazing systems, but in the RGS concentration of grazing was less clustered and the selection of vegetation communities was more homogeneous than in CGS. Under CGS, cows were attracted ($P < 0.05$) to salt placements and areas with high forage pastoral values, and they avoided ($P < 0.05$) steep slopes. In contrast, cows under RGS were not influenced by ($P > 0.05$) high pastoral value, and they avoided areas farther from water ($P < 0.05$). Similar to CGS, cows under RGS were attracted ($P < 0.05$) to salt and avoided ($P < 0.05$) steep slopes. In the RGS, cows used steeper slopes and areas farther from salt and water in the second half of the grazing period within a paddock compared with the first half, which likely explains the improvement in uniformity of grazing with RGS. Our findings indicate that Pastoral Plans that combine appropriate stocking levels and RGS are valid policy and management tools that have the potential to improve grazing distribution on rough sub-alpine and alpine pastures in the south-western Alps.

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Introduction

Livestock have grazed the Alps for thousands of years (Bätzing 2005). The indigenous forests have been fragmented into a mosaic of forest, shrub and grassland patches (Dullinger *et al*. 2003), creating cultural landscapes with semi-natural open habitats of high ecological value (Gellrich *et al*. 2007). Over the past decades, alpine livestock enterprises have become less economically competitive than lowland farms (Mattiello *et al*. 2002; Erschbamer *et al*. 2003) and the income differential between farm and non-farm jobs (Gellrich *et al*. 2007) has led to human depopulation, socioeconomic changes (Tasser and Tappeiner 2002), and a reduction of available manpower in alpine agricultural areas (Camacho *et al*. 2008). As a result, semi-natural grasslands have been abandoned and land use has changed dramatically in several parts of the Alps (MacDonald *et al*. 2000; Freléchoux *et al*. 2007; Jewell *et al*. 2007; Parolo *et al*. 2011; Garbarino *et al*. 2013).

The south-western Italian Alps are one of the alpine regions more deeply affected by this agricultural and pastoral abandonment (Probo *et al*. 2013). The number of small family farms that relied on traditional herding has declined (MacDonald *et al*. 2000) and they have been replaced with a smaller number of larger farms. Historically cattle were moved around grassland areas by herding. In order to reduce labour requirements, continuous grazing systems (CGS) replaced herding-based grazing management, because they require minimal labour and capital inputs. Cattle can be released and allowed to roam freely. Free-roaming livestock in the mountainous terrain of the Alps have resulted in more selective and spatially heterogeneous grazing distribution than in the past, when herding limited the natural preference of animals for gentle topography with herbage of greater mass and higher nutritive value (Bailey 2005). Herders encouraged cattle to use rugged terrain. The combination of uneven livestock distribution and the marked reduction of stocking rates have resulted in widespread undergrazing of the steepest areas in the sub-alpine and alpine belts. As a consequence of limited grazing in many rugged locations for several years, vegetation cover and composition have changed through natural successional processes (Dumont *et al*. 2001; Meisser *et al*. 2009). Herbaceous oligotrophic species, dwarf shrubs, and trees have encroached large areas of semi-natural grasslands (Tasser and Tappeiner 2002; Dullinger *et al*. 2003; Freléchoux *et al*. 2007), reducing the herbage mass and nutritive value of grasses (Kesting 2009), and carrying capacity of grasslands (Bailey *et al*. 1998). MacDonald *et al*. (2000) referred to these changes as 'a loss of landscape heterogeneity and mosaic features, which represents a loss of cultural landscapes'. The encroachment of shrubs and trees represents one of the main threats for the conservation of alpine biodiversity (Anthelme *et al*. 2001; Laiolo *et al*. 2004; Freléchoux *et al*. 2007; Patthey *et al*. 2012; Ascoli *et al*. 2013) and increases the probability of wild-fires (Romero-Calcerrada and Perry 2004; Ascoli *et al*. 2009), erosion, and avalanches (Jewell *et al*. 2007) in the Alps.

For these reasons, the conservation and the restoration of semi-natural grasslands have become one of the main agri-environmental issues in Europe. In the last 3 years, the Piedmont Region (south-western Alps) has promoted the use of extensive grazing for the conservation of biodiversity, soil and landscape. Pastoral Plans have been introduced as a policy tool to enhance livestock pasture use, farm productivity, system sustainability, and rangeland health by identifying specific grazing management actions (Lombardi *et al*.

2011; Argenti and Lombardi 2012). The primary activity has been the implementation of rotational grazing systems (RGS) with relatively large paddocks (i.e. ~100 ha on average) during summer (for at least 80 days) at stocking rates in equilibrium with measured vegetation carrying capacity, as defined by Cavallero *et al*. (2007). One of the main goals of Pastoral Plans is to preserve open habitats by increasing both the stocking density and grazing intensity and improving grazing spatial distribution by enhancing exploitation of steep areas that have received little use under CGS. Briske *et al*. (2008) argued that stocking rate is a more consistent and persuasive management variable than grazing system. For this reason, Pastoral Plans have implemented both a change in the grazing system and in the stocking rate in order to enhance cattle use of pastures. To our knowledge, most of the research evaluating RGS has been carried out in rangeland systems with gentle or moderate terrain (Briske *et al*. 2008; Bailey and Brown 2011). The effectiveness of RGS with large paddocks in rough alpine environments has not been studied extensively.

A case study was conducted in the south-western Alps to compare the spatial distribution of beef cows under a CGS in 2010 and a RGS introduced in 2012 with the implementation of Pastoral Plans. The main objectives were to: (1) describe cattle distribution patterns under the CGS and RGS, (2) analyse the selection of vegetation communities under the CGS and RGS, and (3) identify factors affecting the spatial use of pastures. It was hypothesised that under the RGS: (1) the distribution of cattle grazing would be less spatially aggregated, (2) selection of different vegetation communities would be more homogeneous, and (3) forage pastoral value, a synthetic value summarising herbage mass and nutritive value, would be a less important factor affecting grazing distribution than under the CGS.

Materials and methods

Study area and grazing systems

The study was conducted in Val Troncea Natural Park, Piedmont, North-West Italy (latitude 44°57′N, longitude 6°57′E), which is an area representative of the changes that have occurred on grasslands in the south-western Alps throughout the last decades (i.e. reduction in the number of farms, increase in number of cattle per farm, herds managed under the CGS, and increase of shrub cover). Dominant soils are gravelly and nutrient-poor, originating from calcareous parent rock. Annual average air temperature is 0.8°C (January: –8°C; July: 9.5°C) and annual average precipitation is 956 mm (Biancotti *et al*. 1998). Grasslands are mainly dominated by *Festuca curvula* Gaudin, *Carex sempervirens* Vill. and *Trifolium alpinum* L. The shrub layer was predominantly composed of *Rhododendron ferrugineum* L., *Juniperus nana* Willd., *Vaccinium myrtillus* L., and *Vaccinium gaultherioides* Bigelow, that have rapidly encroached wide areas of grasslands after the decline in agro-pastoral activities. Shrub cover in Val Troncea Natural Park increased from 2% in 1982 (IPLA 1982) to 18% in 2011 (Probo *et al*. 2013).

Within the Park boundaries, one study area was selected in 2010 and a very similar area was selected in 2012 (Table 1). In 2010, the study area consisted of one pasture belonging to one of the two farms still operating in the Park. Pastures of the RGS used during 2012 were chosen to have highly comparable topographic, soil, and vegetation conditions with the CGS in 2010 (Tables 1 and 2) and were partially overlapped with the area of the CGS (126.5 ha overlapped between the two grazing systems, i.e. 22% of the area of the CGS). Monthly precipitation distribution and average temperature (°C) were compared between 2010 and 2012 using Bagnouls–Gaussen thermo-pluviometric diagrams (Fig. 1). The total precipitation (snow and rainfall) for the 2 years was similar (677 and 652 mm, respectively). Total summer precipitation (period from 1 June to 30 September) was similar too (293 and 254 mm, respectively). Despite some differences in monthly precipitation distribution patterns between years (e.g. precipitation peaks in June 2010 and in September 2012, respectively), there were no periods of drought during 2010 or 2012. Precipitation during April–June was sufficient to guarantee water availability for the vegetation in both years (Fig. 1).

In 2011, both farms operating in the Park implemented a RGS on the whole managed area (~1300 and 1600 ha, respectively), following the recommendations of the Pastoral Plans drawn up and approved in the Rural Development Plan 2007–2013 of the Piedmont Region (Lombardi *et al*. 2011). Pastoral Plans subdivided the managed area into 18 paddocks per farm, which were grazed by different herds (4 and 3, respectively), on a rotational basis during the summer period (from the beginning of June to late September). A few paddocks (the ones at the lowest elevation) were grazed twice during the grazing season (i.e. at the beginning and at the end, in order to utilise the regrowth of the vegetation in late September), whereas most of the paddocks were grazed only once. According to the regulations of the Rural Development Plan 2007–2013, paddocks were fenced so that they would support a herd for 2–3 weeks on average with a stocking rate based on recommended levels calculated from botanical composition (and associated forage pastoral value) and terrain characteristics obtained from surveys using the procedures of Daget and Poissonet (1971) and Cavallero *et al*. (2007).

After implementation of Pastoral Plans, stocking rate was increased from 0.67 AUM ha^{-1} to 0.81 AUM ha^{-1}. Due to both the increase in the stocking rate and division of the study area into smaller paddocks (parts of the RGS), stocking density noticeably increased (Table 1).

Cattle and grazing management

The area managed under the CGS was grazed from 13 June to 29 September 2010 by 119 beef cows. Cattle included heifers, lactating cows with calves, and non-lactating cows, varying in age from 1 to 15 years. All cows had prior experience of the pastures. Cattle were predominantly of Piedmontese breeding, with some Valdostana Red Pied and Barà-Pustertaler cows, which are all traditional alpine breeds and well adapted to forage on rugged mountain rangelands.

The area of RGS was grazed from 15 June to 23 September 2012 and consisted of six paddocks (three paddocks per farm). Pastures were grazed once during the summer season (Table 2). During the residual time, cattle grazed in other pastures, following the rotation and grazing schedule prescribed by Pastoral Plans. The average area of paddocks was 99 ± 28.9 ha (mean ± s.e.) and each paddock was grazed for an average of 21 ± 4.04 days. The herd from one farm grazed three pastures, and the herd from the other farm grazed the remaining three pastures. Both herds were composed of beef cows with Piedmontese breeding and consisted of heifers, lactating cows with calves, and non-lactating cows, varying in age from 1 to 15 years.

All cows had prior experience of the pastures, as they had grazed in the study area in previous years. One herd had 122 cows (105 animal units) and the other 150 cattle (130 animal units) and the individual cattle differed between years.

Global positioning system tracking

In 2010, under the CGS, seven randomly-selected cows were tracked with global positioning system (GPS) collars. In 2012, seven randomly selected cows from each of the two herds were tracked. All cows were tracked with GPS Model Corzo collars, which the manufacturer reports as having an average accuracy of 5 m (Microsensory SLL, Fernán Núñez, Andalusia, Spain). Positions were recorded every 15 min so that collars could continuously track cows during the 4-month grazing season each year without changing batteries. Collars were fitted with dual-axis motion sensors, which were sensitive to horizontal and vertical movements of head and neck. They recorded activity in movement counts (255 counts maximum) and provided a single averaged value of vertical and horizontal axis measurements seven times during the 15-min interval between fixes (roughly one value every 2 min). Collars were placed on cows 1 week before the beginning of the study to allow cattle to become accustomed to the GPS collars.

Vegetation and topographic variables

The 2010 and 2012 study areas were subdivided into 150 × 150-m grid cells, which resulted in grids with 285 and 317 cells, respectively (Table 1). To determine botanical composition, a vegetation transect was established in the centre of each grid cell for vegetation surveys using the vertical point-quadrat method (Daget and Poissonet 1971; Jonasson 1988). Transects were 10 m long and vegetation surveys were conducted in summer 2010 for the area of the CGS and in summer 2012 for the area of the RGS. Measurements were collected before grazing and during June–August, at the flowering phenological stage for the dominant graminoids. At 50-cm intervals along each transect, the plant species touching a steel needle were identified and recorded (i.e. 20 points per transect). Ten measurements of the height of the shrub and the herbaceous layers were recorded at random locations within a 1-m buffer around the transect line using the ‘sward stick method’ (Stewart *et al*. 2001). The canopy cover of trees, shrubs and herbaceous vegetation, as well as bare ground and rock cover, were visually estimated for each grid cell.

Starting from the centre of each grid cell, distances to the nearest available water source (stream, trough or pond) and to the nearest salt or mineral mix supplement (MMS) point were calculated. Average slope of each grid square was calculated from the Digital Terrain Model (50-m resolution) of the Piedmont Region (CSI Piemonte 2005). All geographical analyses were conducted using QGis 1.8.0 (Quantum Gis Development Team 2012) and GRASS GIS 6.4.2 (GRASS Development Team 2012).

Data analysis

In order to analyse the patterns of the distribution of grazing by cows, we first identified the time periods that grazing occurred most frequently. We used two variables to classify periods of grazing and not grazing: horizontal distance travelled by cows and the average activity measured by motion sensors every 15 min per each cow (Ungar *et al*. 2005). Grazing periods were identified as times when horizontal distance travelled and motion sensor-based activity were higher and resting periods were assigned time when these values were lower. Comparisons of horizontal distance travelled and motion-sensors readings for the grazing and non-grazing (resting) periods were conducted with the Wilcoxon signed-rank test (Sokal and Rohlf 1995). For all the following analyses, only data recorded during the grazing period were used. Positions recorded during periods classified as resting were excluded.

Patterns of distribution of cows

The spatial distribution of grazing cows under both systems was assessed through univariate point pattern analysis at different spatial resolutions (10-, 20- and 50-m grid cells). Six different raster maps (two pastoral systems × three spatial resolutions) were derived from the GPS positions of grazing cows. We used raster maps rather than GPS positions to minimise spatial autocorrelation and any precision issues with GPS accuracy. Grid maps were transformed to a matrix with two categories of pixels (presence and absence) and a mask was used to take into account the irregular shape of the study areas (space restriction effect). We used the univariate pair-correlation function g(r), that is defined as clumped, random or regular (hyperspersed) if the g(r) values are greater than, equal to or lower than the confidence envelopes (CE^+ and CE^-), respectively (Wiegand and Moloney 2004). We used pair-correlation functions (g) (Stoyan and Stoyan 1994), a second-order statistic that is non-cumulative and allows specific scales to be identified where significant point-point interactions occur (Wiegand *et al*. 2007). In order to compare the spatial pattern of cows under both systems, a measure of relative spatial aggregation was calculated. This index is the ratio between the observed pair-correlation value g(r) and the corresponding upper confidence envelope (CE^+) at a specified distance r (Fajardo *et al*. 2006). The index [$g(r)/CE^+$] was used to compare the CGS and RGS using 10-, 20- and 50-m pixels (i.e. differing grazing systems and spatial resolutions). A completely random spatial pattern was chosen as a null model, built by moving the 'presence pixels' within the raster map. We computed 99% confidence envelopes for $g_{11}(r)$ by running 99 simulations at intervals of 1 m from 1 to 50 m adopting a 1-m lag distance using Programita software (Wiegand and Moloney 2004).

Selection of vegetation communities

For each plant species recorded in the vegetation transects, the frequency of occurrence, which is an estimate of species canopy cover (Gallet and Roze 2001), was calculated. Species relative abundance (SRA) was calculated for each plant species by dividing its frequency of occurrence by the sum of frequency of occurrence values for all species in the transect and multiplying by 100 (Daget and Poissonet 1971; Probo *et al*. 2013). The SRA can be used to detect the proportion of different species. Vegetation transects were classified into vegetation communities (i.e. vegetation types and vegetation ecological groups, Cavallero *et al*. 2007) by cluster analysis using IBM SPSS Statistics 19 (SPSS 2010). The classification variable was SRA, the cluster method was Pearson correlation coefficients, and the between group linkage was the resemblance coefficient. Preference and standardised indices (Hobbs and Bowden 1982; Tomkins *et al*. 2009) were calculated for each vegetation ecological group. Preference indices were calculated as the proportion of GPS records in a given ecological group divided by the proportional area of that vegetation ecological group. A 95% confidence interval with a Bonferroni adjustment (Manly *et al*. 2002) was calculated for each preference index to determine if individual ecological groups were avoided, used indifferently, or preferred by cows. Values >1 for the lower confidence limit indicated preferential selection for a particular ecological group, while values <1 for the upper confidence limit indicated that cows used that particular ecological group proportionally less than its availability would suggest. If the value of 1 was within the confidence interval, it implied that cows were indifferent and used a particular vegetation ecological group in proportion to its presence. In order to analyse monthly variation in the selection of different vegetation ecological groups in the CGS, preference indices were calculated for each month of the grazing season (i.e. for June, July, August, and September).

Factors affecting the distribution of cows

Each plant species was classified according to the Index of Specific Quality (ISQ) (Daget and Poissonet 1971; Cavallero *et al*. 2007). The ISQ is based on preference, morphology, structure, and productivity of the plant species found in the south-western Alps, and it ranges from 0 to 5. In each transect, forage pastoral value, a synthetic value summarising forage yield and nutritive value ranging from 0 to 100 was calculated (Daget and Poissonet 1971). Forage pastoral value for a grid cell was weighted for relative abundance of species in the cell and is calculated using the following equation:

$$PV = \sum_{i=1}^{i=n} (SRA_i \times ISQ_i) \times 0.2$$

where PV is forage pastoral value, SRA_i is species relative abundance, ISQ_i is the index of specific quality value for the species *i*, and *n* is the number of species found on the transect within a grid cell.

Each herbaceous species was also classified as forb, grass, or sedge and total frequency of occurrence of forbs, grasses, and sedges was calculated.

Relationships between vegetation and topographic variables and use by cows of a grid cell under both systems were analysed with Generalised Linear Mixed Models (GLMM, Zuur *et al*. 2009). We used grazing frequency (i.e. the total number of GPS records of the herd in each grid square) as the dependent variable and the following 13 vegetation and topographic variables for each grid square as predictors: tree canopy cover, shrub cover, herbaceous cover, bare ground and rock cover, average height of the shrub layer, average height of the herbaceous layer, forage pastoral value, average slope, distance to nearest available water source, distance to the nearest salt or MMS point, frequency of forbs, frequency of grasses, and frequency of sedges. Predictors were standardised (Z-scores) to allow for analysis of effect size by scrutinising model parameters (β coefficients). A correlation analysis of predictor variable was used to exclude any highly collinear predictors ($r > |0.80|$). In the RGS model, paddock was considered as a random effect. A Negative Binomial distribution was specified for the dependent variable, as it was a count over-dispersed variable (over-dispersion was tested with the qcc R package, Scrucca 2004). Significance tests were performed using the Wald statistic (Dobson 1990) and the final model was selected based on the best goodness of fit from the

Akaike's information criterion (AIC). All analyses were carried out using R 2.15.2 with the glmmADMB package (R Development Core Team 2005).

Repeated-measures analyses (Littell *et al*. 1996) were used to determine if the relationship between use by cows of grid cells and important ($P < 0.05$) vegetation and topographic variables from GLMM analyses changed over time. Dependent variables were averages calculated for each cow during 10-day periods in the CGS and in two periods of the same length (i.e. first and second half of the grazing period) within each pasture in the RGS. For the CGS in 2010, the fixed effect was the 11 10-day periods that cows were tracked. For the RGS in 2012, the fixed effects were paddock, period within paddock (first or second half), and the period by paddock interaction. The subject for the repeated statement was cow. Covariance between repeated records was modelled using autoregressive of order 1, compound symmetry, or unstructured covariance structures (Littell *et al*. 1996). Of the three covariance structures evaluated, unstructured covariance had the lowest AIC value and was used.

Results

In 2010, one collar failed and, in 2012, two collars failed, so tracking data were obtained from six collared cows in 2010 and 12 collared cows in 2012 (seven from one farm and five from the other). A total of 36 337 positions (average of 6056 positions per collar) were recorded during the 2010 deployment period, and 58 503 positions (average of 4875 per collar) were recorded during the 2012 deployment. A marked diurnal pattern was apparent for all collared cows (Fig. 2). From 0600 hours to 2200 hours cows travelled longer distances and were more active ($P < 0.001$) than from 2200 hours to 0600 hours. Accordingly, the grazing period was defined from 0600 hours to 2200 hours. Locations recorded by GPS collars during the grazing period were used in the analyses and included 22 092 records in 2010 and 37 728 in 2012.

Patterns of distribution of cows

The spatial distribution of cows within the CGS and within paddocks in the RGS was aggregated and significantly differed from the random spatial pattern of the null model (Fig. 3). The null model was rejected and the observed pattern g(r) was aggregated at all spatial resolutions (10-, 20- and 50-m pixels). The index of relative aggregation [$g(r)/CE^+$] revealed that the spatial distribution of cows under the CGS was more aggregated than under RGS at all spatial resolutions. The relative difference in the strength of aggregation between the CGS and RGS emerged as being higher at finer resolutions (10 m) and within short distances (spatial distances between 2 and 4 m). A peak of aggregation was observed for r-values ranging between 1 and 6 m. The size of pixels was negatively associated to the strength of aggregation of grazing cows.

Selection of vegetation communities

Vegetation transects were classified into 29 vegetation types and five vegetation ecological groups (Table 3, Fig. 4). Under the CGS, meso-eutrophic and snow-bed ecological groups were preferred ($P < 0.05$), whereas shrub-encroached, oligotrophic, thermic and rocky ecological groups were avoided ($P < 0.05$) by grazing cows (Table 4). Selection of vegetation ecological groups was more homogeneous under the RGS than the CGS, with shrub-encroached, meso-eutrophic, and oligotrophic groups being preferred ($P < 0.05$), the snow-bed group used in proportion to its presence, and thermic and rocky group avoided ($P < 0.05$). A marked monthly variation in the selection of different vegetation ecological groups under the CGS was detected (Fig. 5). In June, grazing cows selected the meso-eutrophic group and avoided all the other groups ($P < 0.05$). In July, the snow-bed group was the most preferred, whereas in August and September selection of different vegetation ecological groups was more homogeneous, with meso-eutrophic and snow-bed groups being the most preferred ($P < 0.05$). The thermic and rocky ecological groups were avoided throughout the entire summer, whereas selection of the shrub-encroached group increased over time, with the group being avoided in June and July, used indifferently in August, and preferred in September ($P < 0.05$).

Factors affecting the spatial use of pastures

Based on the results of the correlation analysis, none of the predictors was excluded from the GLMM analyses. Two final models predicting use by cows of grid cells under the CGS and RGS were selected based on AIC values (Table 5). Under the CGS, cattle preferred grazing areas near salt or MMS placement points ($P < 0.001$), with gentler terrain ($P < 0.01$), and higher forage pastoral values ($P < 0.05$). Under the RGS, pasture use was affected by slope ($P < 0.001$), distance to water ($P < 0.001$) and distance to salt or MMS placement areas ($P < 0.05$), but it was not influenced ($P > 0.05$) by forage pastoral value (Table 5). Herbaceous, shrub, bare ground and rock cover as well as the average height of the herbaceous cover were not important ($P > 0.05$) predictors of use by cattle of pastures neither in the models for both systems.

During the summer in the CGS, cows showed changes ($P < 0.001$) in the use of areas with different forage pastoral values (Fig. 6*a*). They grazed areas with the highest forage pastoral values in June and areas with the lowest values in late September. Temporal variations ($P < 0.001$) in the distance to salt or MMS placement points and in the use of areas with different slopes were also detected (Fig. 6*b*–*c*). In the RGS, cows used steeper areas, grazed further from salt or MMS placement points and water in the second half of the grazing period within a paddock compared with the first half ($P < 0.001$) (Fig. 7*a*–*c*). Paddock and period by paddock interaction were not important (effects ($P > 0.10$).

Discussion

The comparison of CGS and RGS in this study relies on the fact that climatic, topographic, and vegetation features of the study areas in 2010 and 2012 were similar (Table 1). Annual precipitation varied by only 4% during the study years, and summer precipitation varied by 13%. The temperature regimes in 2010 and 2012 were also similar as well as aspect, elevation, slope, and vegetation cover and composition. The similarity of environmental conditions between 2010 and 2012 and the magnitude of the differences in the distribution of cows between the systems (CGS in 2010 and RGS in 2012) suggest that the differences can be attributed primarily to implementation of rotational grazing of paddocks and higher stocking rates in the RGS.

Our results suggest that the implementation of rotational grazing with large paddocks improved the distribution of grazing by cows by an enhanced exploitation of steep areas that were previously infrequently grazed under the CGS. Under rotational grazing of large paddocks and with higher stocking levels, the distribution of cows was less aggregated and the selection of different vegetation communities was more homogeneous than under continuous grazing with lower stocking levels. Introducing rotational grazing of large paddocks and increasing stocking rate to recommended levels (Cavallero *et al*. 2007) appears to be an effective management tool to increase uniformity of grazing in this region of the Alps. This study site is located in a rough alpine environment with a great deal of variation in topography and vegetation communities (Scherrer and Körner 2011; Duparc *et al*. 2013), which makes it difficult to strategically enclose homogeneous areas within large pastures, as suggested for an optimal improvement in grazing distribution by Bailey and Brown (2011). Despite this variability and extremely rugged terrain, results from the repeated-measures analyses provided additional evidence that the RGS was effective in forcing the cows to graze less preferred areas within the pastures. As pointed out by several authors (Ganskopp and Vavra 1987; Pinchak *et al*. 1991; Bailey *et al*. 1998), cattle prefer grazing areas on gentler slopes, closer to water and salt supplements, with higher forage quality and more preferred species, as these areas allow them to maximise the average energy intake rate through optimal foraging (MacArthur and Pianka 1966). After grazing these areas in the first half of the grazing period within a pasture, cows used steeper areas and grazed farther from salt and water in the second half of the grazing period, which is the likely explanation of the general increase in uniformity of grazing with the RGS.

In contrast, results from the CGS showed that free-ranging cows at lower stocking levels over larger areas resulted in a more selective and spatially aggregated grazing pattern. Cows preferred areas with higher forage pastoral values under the CGS, but under the RGS forage pastoral value was not an important predictor of grazing use. Repeated-measures analyses showed that the grazing distribution under the CGS was strongly related in the summer to the changes in the distribution of vegetation growth, phenology, senescence, and nutritional patterns along the altitudinal gradient (Körner 2003). In June, cows preferred young meso-eutrophic vegetation, which was situated at the lowest elevations and was composed of vegetation types with the highest pastoral values. In July, when meso-eutrophic vegetation became more senescent and had a lower nutritive value (Ganskopp and Bonhert 2006), cows moved to the highest elevations (i.e. elevations between 2400 and 2800 m a.s.l.), following vegetation growth and shifting selection towards the snow-bed vegetation group. Although with a low herbage mass due to the short vegetative cycle at extreme climatic conditions (Körner 2003), snow-bed vegetation is highly nutrient-rich and can be very attractive to large herbivores (Björk and Molau 2007). The attractiveness of areas of snow-bed vegetation could be related not only to their nutritive value but also to optimal grazing conditions, as snow-bed vegetation types were located in gentle terrain (the decrease in the average slope use by cows in this period can be seen in Fig. 6*c*), abundance of water sources due to the late snow melt, cooler air temperatures in the warmest month of the year, and less abundance of annoying horse-flies for cattle (Björk and Molau 2007). In August and September, the selection of different vegetation ecological groups was more homogeneous, with meso-eutrophic and snow-bed vegetation groups (i.e. the ones with the highest forage pastoral values, see Table 3) being always the most preferred. Constant, though diminished preference for the meso-eutrophic vegetation group in the last part of the summer season could be attributed to the preference by cows for vegetative regrowth in these areas over ungrazed areas of other vegetation groups. Vegetative regrowth is frequently preferred by grazing animals, as the proportion of younger plant tissues with high forage quality is higher than in ungrazed areas (Walker *et al*. 1989). Furthermore, a significant increase in the use of shrub-encroached areas was detected in the same period. Increased exploitation of this low forage pastoral value group (the decrease in the average forage pastoral value used by cows in this period can be seen in Fig. 6*a*) in September may be related to low herbage masses within the heavily grazed meso-eutrophic and snow-bed vegetation areas, which forced cows to graze less favourable areas to maintain their daily intake rate. Shrubs in the study area are generally not palatable to cattle. Overall, vegetation structure and composition within the study area appear to be drivers of the distribution of grazing by cows, confirming that patterns of herbage utilisation in an extensive CGS have probably been consistent across years (Ganskopp and Bonhert 2006). Repeated intense and early season grazing of the meso-eutrophic vegetation group would have likely maintained these grazing-tolerant and nutrient-demanding vegetation areas, while the limited and late-season use of shrub-encroached areas by cows may have not been sufficient to prevent progressive encroachment by dwarf shrubs (Tasser and Tappeiner 2002; Camacho *et al*. 2008).

In both grazing systems, the average height of the herbaceous layer, which is usually positively correlated with herbage mass (Porté *et al*. 2009), did not affect grazing distribution. Cattle generally allocate the time that they spend in an area within a pasture in proportion to the resource level found there, usually in terms of the herbage mass of nutrients or nutrient concentration rather than the herbage mass of dry matter (Senft *et al*. 1985; Pinchak *et al*. 1991). Several authors have emphasised the importance of water in influencing the spatial distribution of cattle in different rangeland systems, with cattle always preferring areas close to water sources (Valentine 1947; Putfarken *et al*. 2008; Bear *et al*. 2012). However, proximity to water affected grazing distribution only under the RGS, whereas it was not an influential factor under the CGS. This result may be related to the preference for the flattest areas with the highest pastoral values by cows under the CGS. This preference for gentle terrain with herbage of high nutritive value may be strong enough that cows are willing to travel from the relatively abundant sources of water within this mountainous study area with perennial and summer seasonal streams.

This case study highlighted the beneficial effects produced by the implementation of Pastoral Plans (increasing stocking rates and using a rotational grazing system with large paddocks) in reducing selectivity by cows and improving the distribution of grazings. The implementation of the RGS with a relatively small number of large paddocks appears to be a sustainable and practical management system in the Alps because it requires less labour and fencing than rotational grazing systems with a large number of small paddocks. Because the Rural Development Plan 2007–2013 prescribes that Pastoral Plans be implemented for 5 consecutive years, future research should evaluate if this policy will help conserve open habitats during this medium-term period. In particular, assessment of the changes in the pastoral value of grasslands appears warranted, as well as evaluation of the changes in grassland carrying capacity and biodiversity, which are key conservation objectives on natural protected areas. Increased uniformity of defoliation across plant species and vegetation communities on steep locations under the RGS should help ensure that key plant species (i.e. grazing-tolerant and nutrient-demanding grassland species) capture sufficient resources (e.g. light, water and nutrients) to enhance growth, in order to be more competitive with grazing-intolerant oligotrophic species (Briske *et al*. 2008). Pastoral Plans recommend the implementation of supplementary actions in order to farther improve grazing distribution, such as the strategic placement of drinking troughs and MMS to attract livestock into underused areas (Probo *et al*. 2013; Tocco *et al*. 2013). Additional research on the synergistic effects produced by the combined implementation of these management practices should be considered.

Conclusions

Management of domestic herbivores is an important tool to manipulate the cover and botanical composition of alpine grasslands. Throughout the last decades, increased selective and spatially heterogeneous grazing of free-ranging livestock has resulted in a widespread tree and shrub-encroachment of open habitats in the south-western Alps. Based on this case study, Pastoral Plans using a rotational grazing system with large paddocks and a higher stocking levels appear to have the potential to reverse this process, by reducing cattle selectivity and improving grazing distribution on rugged alpine environments.

Given the need to preserve remaining pastoral activities as an effective management tool for the conservation of mountain semi-natural open habitats, agri-environmental incentives should be more and more directed to support the best grazing practices in the future. Agri-environmental schemes supporting the implementation of Pastoral Plans can be valid policy measures to be considered for the conservation of cultural open landscapes with high ecological value.

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Table 1. Management, vegetation, topographic, and climatic characteristics of the study areas used in 2010 (continuous grazing systems, CGS) and 2012 (rotational grazing systems, RGS) within Val Troncea Natural Park in the south-western Alps of Italy

	Study area 2010	Study area 2012
Grazing system	CGS	RGS
No. of farms	1	2
No. of herds	1	2
No. of pastures	1	6 (3 + 3)[D]
No. of cattle	119	272 (122 + 150)[D]
Season of grazing	13 June–29 September	15 June–23 September
No. of animal units (AU)[A]	105	235 (105 + 130)[D]
No. of cows with GPS-collars	7	14 (7 + 7)[D]
Stocking rate (AUM[B] /ha^{-1})	0.67	0.81
Average stocking intensity (AU ha^{-1})	0.18	1.86
Area (ha)	572.3	591.4
Grassland cover (%)	49.2	53.1
Shrub and rock cover (%)	50.8	46.9
Tree canopy cover (%)	12.9	4.5
Average aspect[C]	0.82	0.87
Minimum elevation (m)	1855	1911
Average elevation (m)	2328	2491
Maximum elevation (m)	2789	2928
Average slope (°)	23.8	25.7
No. of salt and mineral mix supplement points	14	16
No. of vegetation transects	285	317

[A]AU = one mature, non-lactating bovine weighing 500 kg (Allen *et al*. 2011).

[B]AUM = AU · months of grazing.

[C]Aspect rescaled following heat load index equation by McCune and Keon (2002). The heat load index equation rescales aspect to a scale of zero to one, with zero being the coolest slope (north-east) and one being the warmest slope (south-west).

[D]Data within brackets are divided for the two farms.

Table 2. Area, topographic characteristics, grazing schedule, and average pastoral value of the six pastures selected in 2012 (rotational grazing systems, RGS) within Val Troncea Natural Park in the south-western Alps of Italy

Pasture	Farm	Area (ha)	Grassland cover (%)	Grazable area (ha)	Shrub and rock cover (%)	Average altitude (m)	Average slope (°)	Starting date	Ending date	Days of grazing	Average pastoral value
1	Giletta	27.98	0.817	22.87	0.183	2015	24.2	15 June	1 July	17	19.3
2	Giletta	52.50	0.549	28.85	0.451	2264	26.3	15 July	6 Aug.	23	14.8
3	Giletta	241.35	0.459	110.71	0.541	2564	26.8	12 Aug.	23 Sept.	43	10.4
4	Raso	100.07	0.637	63.77	0.363	2482	26.0	11 July	28 July	18	12.9
5	Raso	118.39	0.496	58.69	0.504	2544	24.0	28 July	10 Aug.	14	14.1
6	Raso	51.06	0.570	29.09	0.430	2534	23.5	20 Aug.	1 Sept.	13	15.1

Table 3. Vegetation ecological groups, vegetation types, phyto-sociological plant communities, and forage pastoral values of continuous grazing system (CGS) study area in 2010 and rotational grazing system (RGS) study area in 2012

Vegetation ecological group	Vegetation type	Phytosociological plant communities	Forage pastoral value	Proportion of study area CGS (%)	Proportion of study area RGS (%)
Intermediate meso-eutrophic conditions	*Dactylis glomerata*	*Polygono-Trisetion*	38.0	2.75	0.18
	Festuca gr. *rubra* and *Agrostis tenuis*	*Nardo-Agrostion tenuis*	24.9	3.93	0.63
	Festuca gr. *violacea*	*Caricion ferrugineae*	15.3	6.99	8.52
	Geum montanum	Transition between *Nardion strictae* and *Poion alpinae*	11.1	0.92	1.77
	Trisetum flavescens	*Polygono-Trisetion*	25.3	0.79	0.76
Intermediate oligotrophic conditions	*Calamagrostis villosa*	*Calamagrostion villosae*	2.3	5.34	0.00
	Carex sempervirens	*Caricion curvulae*	12.9	8.71	11.22
	Festuca flavescens and *Juniperus nana*	*Piceion excelsae*	13.0	0.98	0.39
	Nardus stricta	*Nardion strictae*	21.9	5.59	0.97
	Trifolium alpinum and *Carex sempervirens*	*Caricion curvulae*	19.6	2.24	8.94
Shrub-encroached grasslands	*Juniperus nana*	*Junipero-Arctostaphyletum*	14.0	8.46	3.23
	Rhododendron ferrugineum	*Rhododendro-Vaccinion*	5.3	6.66	1.14
	Vaccinium gaultherioides	*Loiseleurio-Vaccinion*	8.2	5.35	6.85
Snow-bed conditions	*Alopecurus gerardi*	Transition between *Nardion strictae* and *Salicion herbaceae*	17.2	0.00	3.03
	Plantago alpina	Transition between *Nardion strictae* and *Salicion herbaceae*	15.9	2.36	2.45
	Salix herbacea	*Salicion herbaceae*	18.5	2.75	9.40
	Salix retusa	*Arabidion caerulae*	7.1	0.39	0.38
Thermic and rocky conditions	*Brachypodium rupestre*	*Bromion erecti*	9.2	0.18	0.32
	Carex rosae	*Seslerion variae*	7.6	4.08	1.85
	Elyna myosuroides	*Oxytropido-Elynion*	8.5	2.08	7.02
	Festuca curvula	*Bromion erecti*	16.8	14.88	11.57
	Festuca quadriflora	*Caricion firmae*	4.0	3.02	6.02
	Festuca violacea and *Saxifraga oppositifolia*	*Thlaspion rotundifolii*	15.3	4.01	7.34
	Helictotrichon parlatorei	*Avenion sempervirentis*	13.1	1.23	0.90
	Onobrychis viciifolia	*Bromion erecti*	25.9	0.39	0.00
	Oxytropis helvetica and *Polygonum viviparum*	*Oxytropido-Elynion*	14.0	1.18	1.96
	Phleum bertoloni and *Festuca curvula*	*Bromion erecti*	22.1	1.13	0.10

Salix serpyllifolia	*Oxytropido-Elynion*	10.9	2.16	2.13
Sesleria varia	*Seslerion variae*	9.4	1.46	0.95

Table 4. The proportion of GPS records and area, preference index (with a 95% confidence interval with a Bonferroni adjustment), and standardised index for each vegetation ecological group under continuous (CGS) and rotational (RGS) grazing systems

	CGS						RGS					
				95% Bonferroni interval						95% Bonferroni interval		
Vegetation ecological group	Proportion GPS records[A]	Proportion area[B]	Preference index[C]	Lower limit	Upper limit	Standardised index[D]	Proportion GPS records	Proportion area	Preference index	Lower limit	Upper limit	Standardised index
Intermediate meso-eutrophic conditions	0.315	0.154	2.05	1.99	2.10	0.35	0.125	0.118	1.06	1.02	1.10	0.21
Intermediate oligotrophic conditions	0.171	0.228	0.75	0.72	0.78	0.13	0.225	0.214	1.05	1.02	1.07	0.20
Shrub-encroached grasslands	0.145	0.205	0.71	0.68	0.74	0.12	0.129	0.112	1.15	1.11	1.19	0.22
Snow-bed conditions	0.089	0.055	1.61	1.52	1.70	0.27	0.148	0.152	0.98	0.95	1.01	0.19
Thermic and rocky conditions	0.279	0.358	0.78	0.76	0.80	0.13	0.373	0.404	0.92	0.91	0.94	0.18

[A]Count of GPS records per vegetation ecological group/total count of GPS records.

[B]Extent of vegetation ecological group/total extent of study area.

[C]Proportion GPS records/Proportion area (Hobbs and Bowden 1982).

[D]Preference index per vegetation ecological group/sum of preference indices for all vegetation ecological groups (Manly *et al*. 2002).

Table 5. Coefficients for environmental variables affecting spatial use of pastures by cattle under continuous (CGS) and rotational (RGS) grazing systems in Negative Binomial models

	CGS			RGS		
	Stand. B[A]	s.e.[B]	*P*-value	Stand. β	s.e.	*P*-value
Intercept	3.65	0.08	<0.001	4.90	0.24	<0.001
Herbaceous cover	1.73	1.81	n.s.[C]	–3.61	23.27	n.s.
Bare ground and rock cover	1.81	1.89	n.s.	–4.61	25.79	n.s.
Shrub cover	1.75	1.82	n.s.	–2.64	16.07	n.s.
Slope	–0.23	0.09	<0.01	–0.30	0.07	<0.001
Forage pastoral value	0.20	0.09	<0.05	0.13	0.08	n.s.
Height of the herbaceous layer	0.12	0.08	n.s.	–0.07	0.08	n.s.
Distance to water	–0.10	0.18	n.s.	–0.42	0.12	<0.001
Distance to salt or MMS points	–2.25	0.18	<0.001	–0.25	0.11	<0.05

[A]Stand. β indicates that each coefficient of the variables (β) has been standardised, that is, measured from their means in units of standard deviations.

[B]s.e. is of standardised coefficients (β).

[C]n.s. indicates not significant ($P > 0.05$).

Fig. 1. Bagnouls–Gaussens thermo-pluviometric diagrams for the years 2010 and 2012 in the study area. The sum of monthly precipitation (left axis, solid line) and average temperature (right axis, dotted line) were reported using a 2 : 1 scale, according to Bagnouls and Gaussen (1957). The intersection of the precipitation curve with the average temperatures would indicate a drought period.

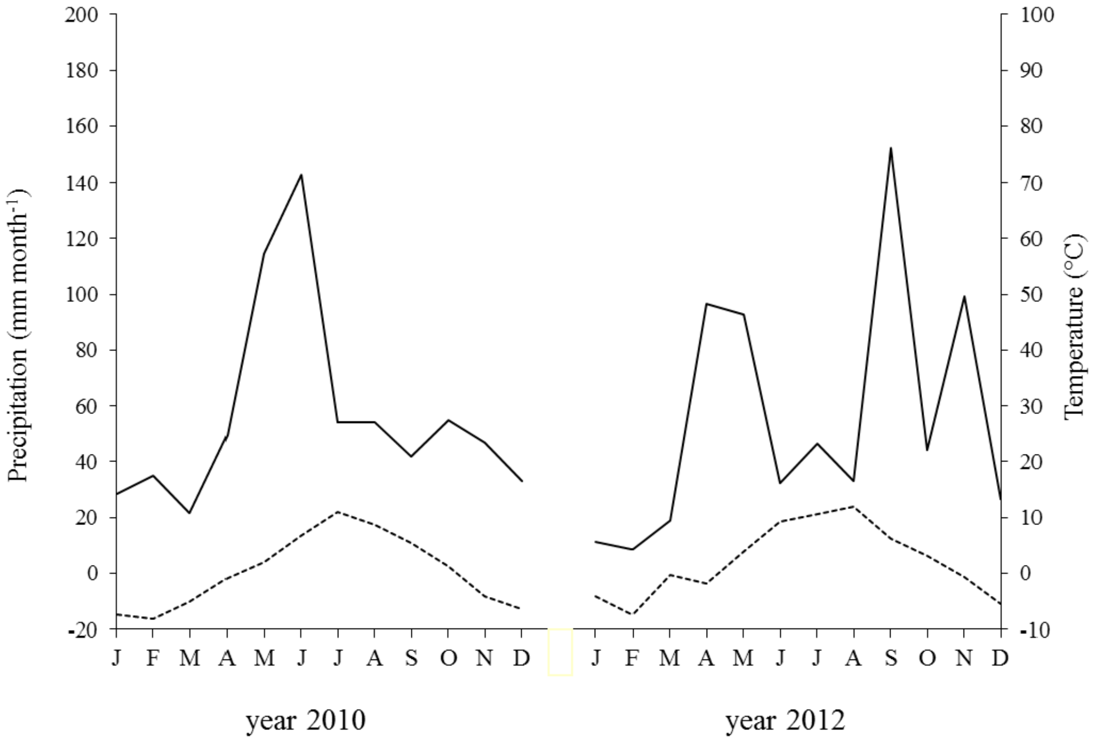

Fig. 2. Mean distance travelled and activity measured by motion sensors every 15 min for cows fitted with GPS collars during the summer (June–September) in the south-western Alps, Italy. Error bars represent the standard error of the means.

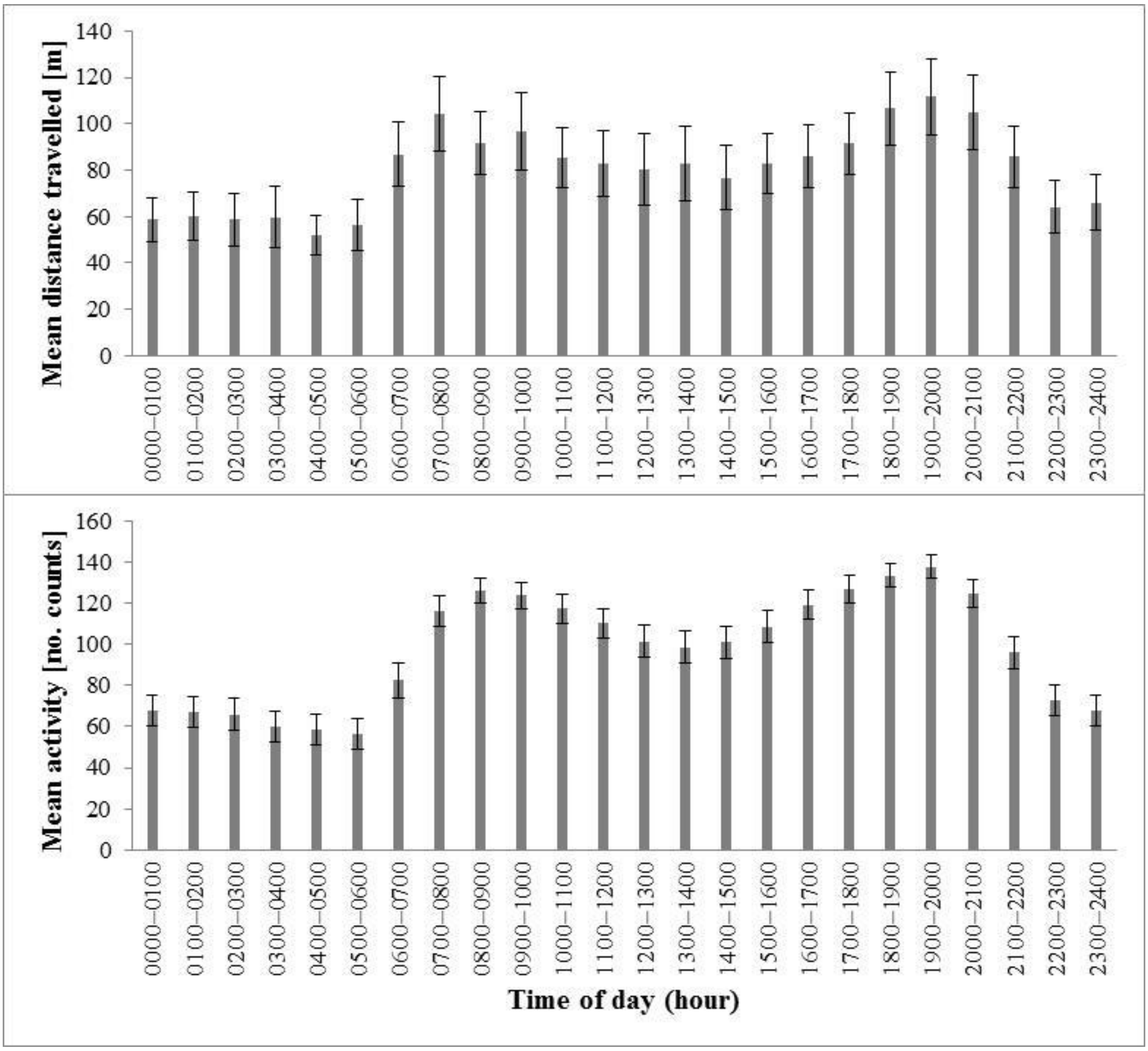

Fig. 3. Ratio between pair correlation value and confidence envelope [g(r)/CE] against spatial distances (r). Continuous lines represent continuous grazing system (CGS), dotted lines represent rotational grazing system (RGS) and shades of grey indicate spatial resolutions (10-, 20-, and 50-m pixel size).

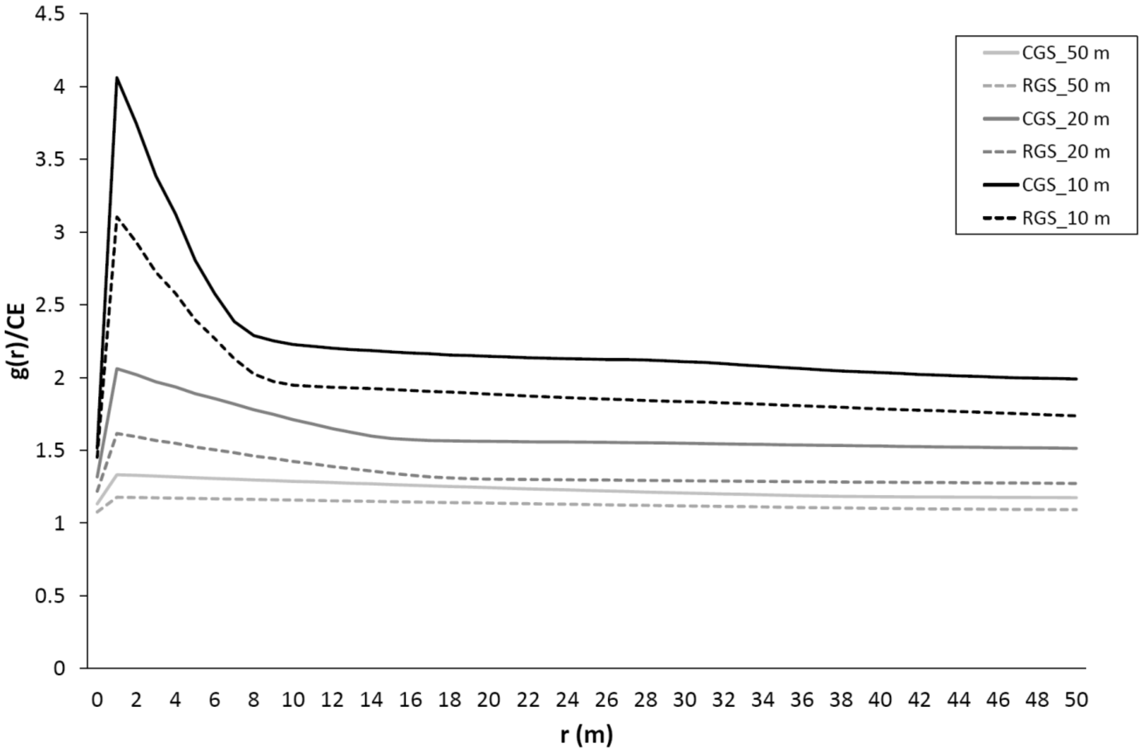

Fig. 4. Location of vegetation ecological groups in the study area in Val Troncea, Western Alps (in set), Piedmont, Italy (UTM zone 32 north, WGS84 datum).

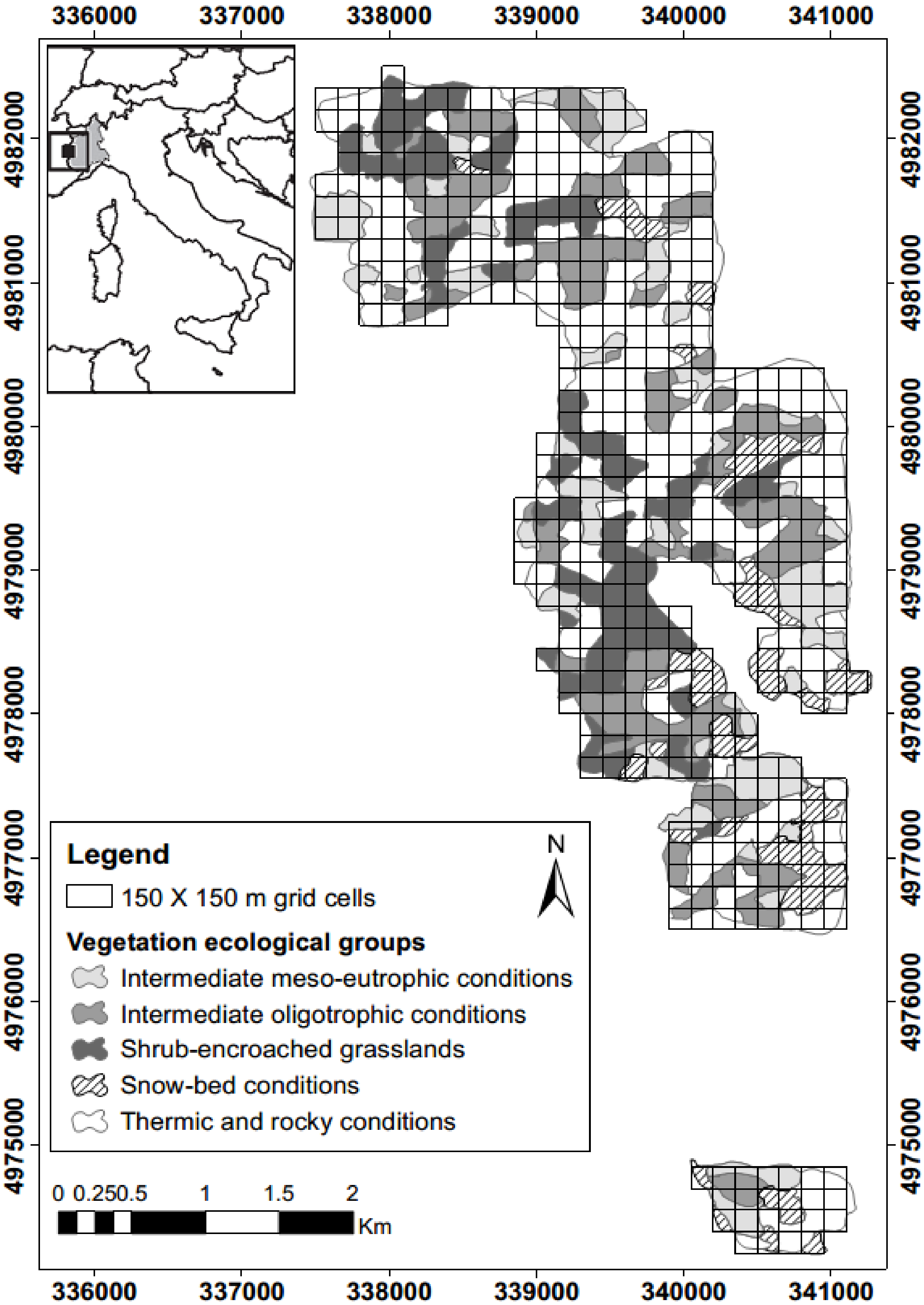

Fig. 5. Monthly variation of preference indices for five different vegetation ecological groups by grazing cattle under continuous grazing system (CGS). [1]Proportion of GPS records in a given vegetation ecological group divided by the proportional area of that vegetation ecological group. Error bars represent 95% confidence interval with a Bonferroni adjustment (Manly *et al*. 2002). Dotted line represents the limit between preference (values >1) and avoidance (values <1).

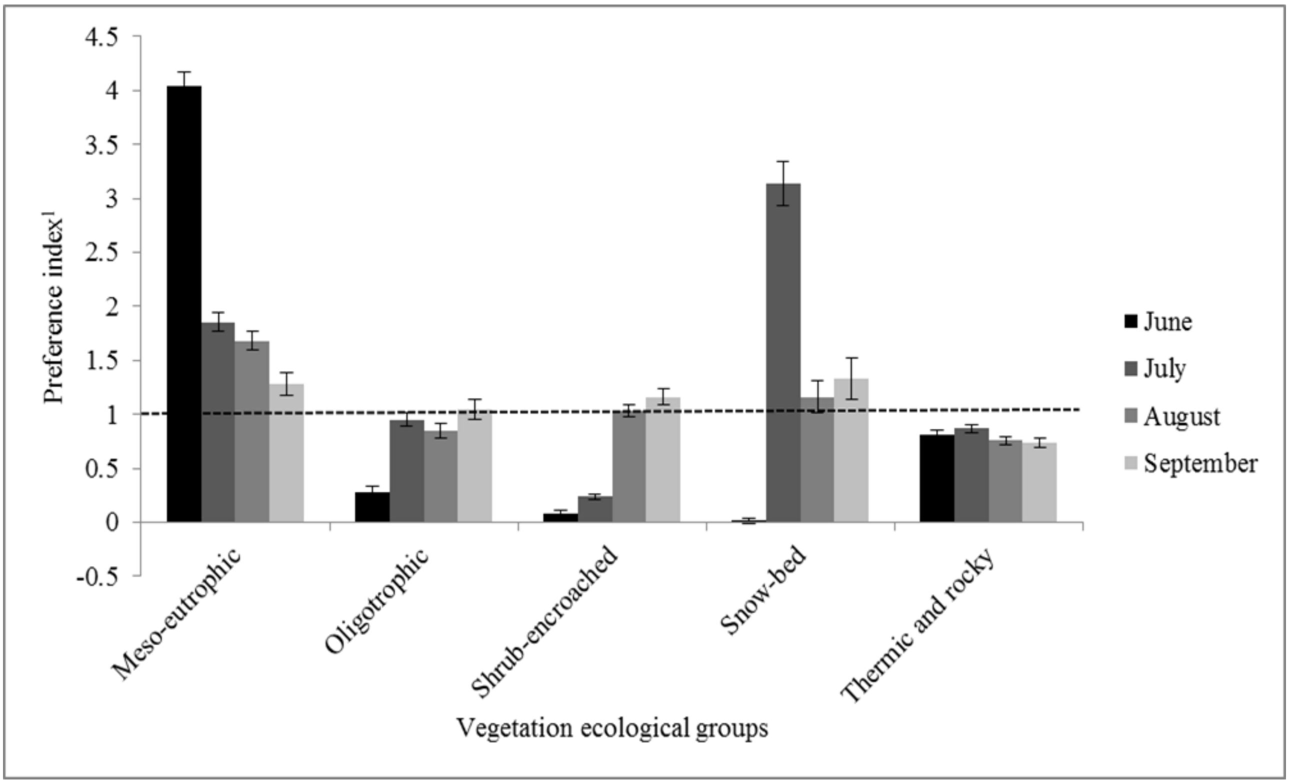

Fig. 6. Temporal variation in mean (*a*) forage pastoral values, (*b*) distance to salt or mineral mix supplement (MMS) placement points, and (*c*) slope of areas (150 × 150-m grid cells) selected by grazing cattle under continuous grazing system (CGS) during 11 10-day periods in the summer season (from 13 June to 29 September 2010). Periods with no letters in common were significantly different ($P < 0.05$). Error bars represent the standard error of the means.

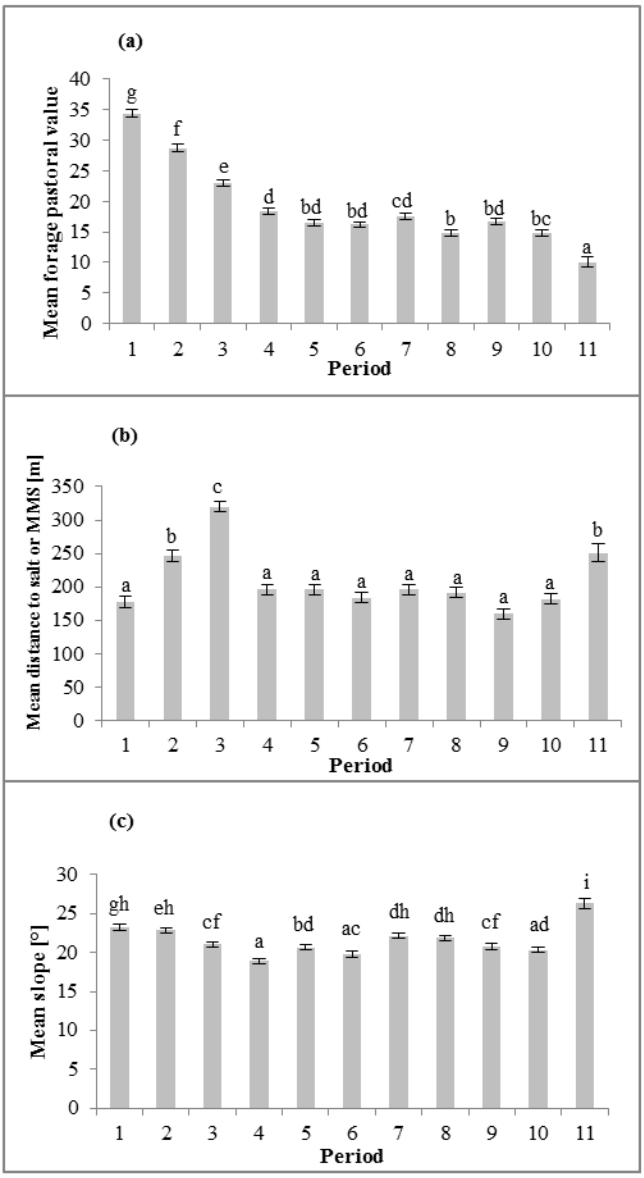

Fig. 7. Temporal variation in mean (*a*) distance to salt or mineral mix supplement (MMS) placement points, (*b*) distance to water, and (*c*) slope during the first (period 1) and in the second (period 2) half of the grazing period within pastures under the rotational grazing system (RGS). Periods with no letters in common were significantly different ($P < 0.05$). Error bars represent the standard error of the means.