UNIVERSITÀ
DEGLI STUDI
DI PADOVA

Sede Amministrativa: Università degli Studi di Padova

Dipartimento di Agronomia Ambientale e Produzioni Vegetali

SCUOLA DI DOTTORATO DI RICERCA IN SCIENCE DELLE PRODUZIONI VEGETALI
INDIRIZZO: AGRONOMIA AMBIENTALE
CICLO XXII

CLASSIFICATION AND BIODIVERSITY PATTERNS IN PASTURES OF PROVINCE OF TRENTO

Direttore della Scuola: Ch.mo Prof. Andrea Battisti
Coordinatore d'indirizzo: Ch.mo Prof. Antonio Berti
Supervisore: Ch.mo Prof. Antonio Berti

Dottorando: Matteo Dainese

Declaration

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Matteo Dainese, July 31st 2010

A copy of the thesis will be available at *http://paduaresearch.cab.unipd.it/*

Dichiarazione

Con la presente affermo che questa tesi è frutto del mio lavoro e che, per quanto io ne sia a conoscenza, non contiene materiale precedentemente pubblicato o scritto da un'altra persona né materiale che è stato utilizzato per l'ottenimento di qualunque altro titolo o diploma dell'università o altro istituto di apprendimento, a eccezione del caso in cui ciò venga riconosciuto nel testo.

Matteo Dainese, 31 Luglio 2010

Una copia della tesi sarà disponibile presso *http://paduaresearch.cab.unipd.it/*

To Federica and Sofia

INDICE

SUMMARY

In the Italian Alps, summer pastures are still managed in traditional ways, which maintain important grassland habitats of many species, although the number of pastures has declined drastically over the past few decades. Research on alpine pastures is important in many respects. From the aspect of nature protection, pastures represent a habitat for numerous plant and animal species; and, through their diversity, contribute greatly to the biodiversity and scenic value of the area. From the economic standpoint, grasslands are a source of feed for stock, a habitat for medicinal and melliferous plants. They are also capable of supporting particular dairy products, high added value, because fodder obtained from natural with unique qualities and not reproducible, capable of giving products derived valuable characteristics and identification.

Land use changes constitute a threat to the persistence of these grassland ecosystems Therefore, it is very important to understand the mechanisms leading to the organization and distribution of these communities to preserve plant diversity and to develop effective agri-environment schemes, which can maintain and enhance biodiversity.

Phytosociological investigation is important to understand some aspects of the study of grasslands. As in the forestry sector, also in grasslands sector have arisen in recent years some efforts to characterize, according to a typological approach, pasture vegetation. A purpose of this research was to realize an interpretative classification of pastures of Province of Trento. Since the pastures of the study area have not been systematically investigated for a long time, the pasture vegetation of the Province of Trento was classified using numerical methods, then the results were compared with the traditional syntaxonomic system, and finally were examined the influence of ecological factors on variation in grassland vegetation.

Further aim of the research was assessed the relationship between topography, distance from the farm centre, altitude, bedrock, grazing intensity, species richness and vegetation composition across two spatial scales (within and between summer farms). A stratified random sampling design was used to

collect 157 vegetation relevés along an elevation gradient. It was hypothesized that plant diversity varies in response to topography due to the highly variable alpine environment and it depends strongly not only on grazing spatial gradient from the centres of the farms to the surrounding vegetation, but also on spatial distribution of the management practices within the study region The patterns of species richness and species composition found in alpine pastures result from the interaction of different environmental and management factors operating at different spatial scales. The results indicate that at small scales (within farms) species richness is mainly determined by slope, while specie composition is controlled by distance from the farm centre as well as slope. At large scale (between farms), was observed a key role of grazing intensity and bedrock types on species diversity patterns. The results indicate that the identification of appropriate stocking rates appears to be the most promising approach to conserve the high biodiversity of alpine pastures, as both intensification and abandonment changed species composition and reduced plant species diversity.

Finally, to gain insight into the processes that may affect species diversity and functional diversity in alpine pastures, the observed local patterns of additive species diversity components (α-, β-, γ-) were analysed with respect to altitude, landscape, topographic hetereogeneity, bedrock type and grazing intensity. Additive diversity partitioning approach facilitated a quantification and comparison of the relative contributions of α- and β-diversity components to total regional diversity along an elevation gradient. Based on the results, I conclude that the observed patterns of plant species diversity appeared to be influenced by processes at multiple spatial scales. The results indicate that the maintenance of a large variety of grassland utilisation systems along with heterogeneous abiotic environmental conditions appears to be a promising tool for the conservation of species richness and functional diversity due to enhanced β-diversity among pastures parcels.

RIASSUNTO

Nelle Alpi italiane, gli alpeggi sono ancora gestiti in maniera tradizionale, conservando importanti habitat e specie vegetali, sebbene il numero delle malghe monticate sia diminuito drasticamente negli ultimi decenni. La ricerca sui pascoli alpini è importante sotto molti aspetti. Dal punto di vista della protezione della natura, i pascoli rappresentano l'habitat di numerose specie vegetali ed animali e attraverso la loro ricchezza di specie, contribuiscono notevolmente alla biodiversità ed al valore paesaggistico delle Alpi. Dal punto di vista economico, i pascoli sono una fonte di alimentazione per gli animali, ed habitat per piante officinali e mellifere. Sono anche in grado di supportare prodotti lattiero-casearii particolari, ad alto valore aggiunto, perché ottenuti da foraggi naturali con caratteristiche uniche e non riproducibili, in grado di dare prodotti derivati di qualità.

I cambiamenti di uso del suolo costituiscono una minaccia per la persistenza di questi ecosistemi. Pertanto, è molto importante comprendere i meccanismi che controllano l'organizzazione e la distribuzione di queste comunità, per preservare la diversità delle piante e di sviluppare efficaci schemi agro-ambientali, in grado di mantenere e migliorare la biodiversità.

L'analisi fitosociologia è importante per comprendere alcuni aspetti dello studio delle praterie. Come nel settore forestale, anche in quello pastorale sono iniziati negli ultimi anni alcuni progetti per caratterizzare, secondo un approccio tipologico, le vegetazioni pascolive. Uno degli obiettivi di questa ricerca era quello di realizzare una classificazione interpretativa dei pascoli della Provincia di Trento. Poiché i pascoli della zona oggetto di studio non sono mai stati studiati in modo sistematico, la vegetazione dei pascoli della Provincia di Trento è stata classificata utilizzando metodi numerici; i risultati sono stati confrontati con il sistema tradizionale sintassonomico e, infine, è stata analizzata l'influenza dei fattori ecologici sulla variazione della composizione floristica dei pascoli.

Un successivo obiettivo della ricerca era quello di valutare la relazione tra la topografia, la distanza dal centro aziendale, l'altitudine, il tipo di substrato geologico, l'intensità di pascolamento, la ricchezza di specie e la composizione della vegetazione attraverso due scale spaziali (all'interno e tra le malghe

campionate). Un disegno sperimentale stratificato è stato utilizzato per campionare i 157 rilievi vegetazionali lungo un gradiente altitudinale. E' stato ipotizzato che la diversità vegetale varia in risposta della topografia legata all'ampia variabilità ambientale degli ambienti alpini, e dipende in modo consistente non solo dal gradiente spaziale di pascolamento dal centro della malga alle vegetazioni marginali, ma anche dalla distribuzione spaziale delle pratiche gestionali impiegate nell'area di studio. I modelli di distribuzione della ricchezza di specie e della composizione riscontrati nei pascoli alpini derivano dall'interazione di diversi fattori ambientali e gestionali che operano a diverse scale spaziali. I risultati indicano che su piccola scala (all'interno delle malghe), la ricchezza di specie è principalmente controllata dalla pendenza, mentre la composizione vegetazionale è determinata dalla distanza dal centro della malga, e dalla pendenza. Su larga scala (tra le malghe), è stato osservato un ruolo chiave dell'intensità di pascolamento e del tipo di substrato geologico sulla ricchezza di specie. I risultati indicano che l'individuazione di appropriati indici di carico animale sembra essere l'approccio più promettente per la conservazione della biodiversità dei pascoli alpini, poiché, sia l'intensificazione gestionale che l'abbandono cambiano composizione delle specie e riducono la diversità delle specie vegetali.

Infine, al fine di conoscere i processi che possono influenzare la diversità delle specie e, la diversità funzionale nei pascoli alpini, i diversi componenti additivi della biodiversità (diversità -α, -β e -γ) sono stati analizzati in relazione all'altitudine, alle variabili del paesaggio, dell'eterogeneità topografica, del tipo di substrato geologico e l'intensità di pascolamento. L'approccio della partizione additiva della diversità facilita la quantificazione ed il confronto tra i contributi relativi delle componenti -α-e –β della diversità rispetto al totale delle diversità regionale lungo un gradiente altitudinale. Sulla base dei risultati ottenuti, è stato osservato che la diversità vegetale sembra essere influenzato dai processi operanti a differenti scale spaziali. I risultati indicano che il mantenimento di una grande varietà di tipi gestionali, insieme alle condizioni ambientali eterogenee delle zone alpine sembra essere uno degli strumenti più favorevoli per la conservazione delle ricchezza di specie e della diversità funzionale, contribuendo ad aumentare la diversità β tra i pascoli.

CHAPTER 1

GENERAL INTRODUCTION:
CLASSIFICATION AND BIODIVERSITY PATTERNS IN PASTURES OF PROVINCE OF TRENTO

Since the second half of the 20th century, changes in land use associated with the intensification of agriculture have been the major cause of losses in farmland biodiversity at local, regional and global scales (Norris 2008). Over the last few decades in many European countries, flat and more accessible areas have been managed more intensively, whereas hilly and mountain areas have been abandoned (MacDonald et al. 2000; Mottet et al. 2006; Tasser and Tappeiner 2002).

In the Italian Alps, summer pastures (mainly for cows and sheep) are still managed in traditional ways, which maintain important grassland habitats of many species, although the number of pastures has declined drastically over the past few decades. Research on alpine pastures is important in many aspects. For nature protection, pastures represent a habitat for numerous plant and animal species; and, through their diversity, contribute greatly to the biodiversity and landscape value of the area. From the economic standpoint, grasslands are a source of feed for stock, a habitat for medicinal and melliferous plants. They are also capable of supporting particular dairy products, high added value, because fodder obtained from natural with unique qualities and not reproducible, capable of giving products derived valuable characteristics and identification.

Land use changes constitute a threat to the persistence of these grassland ecosystems (Dullinger et al. 2003; Spiegelberger et al. 2006). Therefore, it is very important to understand the mechanisms leading to the organization and distribution of these communities to preserve plant diversity and to develop effective agri-environment schemes, which can maintain and enhance biodiversity.

Phytosociological investigation– i.e. classification of grassland communities – is important for all aspects of the study of grasslands. As in the forestry sector, also in grasslands sector have arisen in recent years some efforts to characterize, according to a typological approach, pasture vegetation. In the Alps, over the last years phytosociological and agronomic research on alpine pastures has been conducted through the realization of classification and interpretation manuals of pasture types, as in Veneto (Ziliotto et al. 2004) and in Piemonte (Cavallero et al. 2007).

Environmental conditions and vegetation composition in the European Alps vary due to broad-scale factors such as altitude, precipitation or geographic location, reflecting different climatic conditions, and fine-scale site factors, like variation in slopes, aspects, and soils (Ellenberg, 1996; Wohlgemuth

1998; Moser et al. 2005; Marini et al. 2008b). Local grasslands factors have been demonstrated to be important drivers of plant diversity due to different management (Klimek et al. 2007; Raatikainen et al. 2007; Rudmann-Maure et al. 2008), topography (Sebastià 2004; Bennie et al. 2006) and soil properties (Critchley et al. 2002; Marini et al. 2007).

Functional trait diversity (FD, the extent of trait differences in a unit of study; Tilman 2001; Petchey & Gaston 2002; Wilson 2007) is one of the most relevant components of biodiversity affecting ecosystem functioning (Díaz & Cabido 2001; Hooper et al. 2005; Mason et al. 2005; Díaz et al. 2007). Understanding spatial patterns of FD is important because it reveals the operation of non-neutral community assembly rules (Weiher & Keddy 1995; Stubbs & Wilson 2004; Cornwell et al. 2006; Mason et al. 2007; Mouillot et al. 2007; Petchey et al. 2007). Therefore, by comparing observed patterns in FD to null expectations, it is possible to test different hypotheses about community assembly that determine trait convergence and divergence among species

The partitioning of biodiversity into different spatial components is critical to understand processes underlying species distributions and diversity turnover (Magurran 2004; Ackerly & Cornwell 2007; Prinzing et al. 2008; de Bello et al. 2009). In particular, proper management of ecosystems requires that we understand the processes by which β-diversity (i.e. the diversity across habitats or communities) is generated and maintained (Legendre et al. 2005). As plant species distributions in a landscape are the result of processes operating at both local and regional spatial scales (Collins et al. 2002; Huston 1999; Ricklefs 1987), it is essential to quantify species diversity at multiple scales.

However, these factors and their relative importance for pasture are insufficiently known in the Alps, because only relatively few studies, most in the northern Alps (Muller et al. 2003; Kleijn and Müller-Schärer 2006) have examined the species richness and the species composition of this vegetation community.

Hence, the general aim of this thesis was to evaluate the relative importance of local and landscape factors controlling diversity patterns of vascular plant in pasture environment. The specific objectives of each chapter were reported in the following section:

CHAPTER 2: Classification of pasture communities in the Province of Trento

The purpose of this chapter was to realized and interpretative classification of pastures of Province of Trento. Since the pastures of the study area have not been systematically investigated for a long time, the main tasks of this work are: (1) to classify the pasture vegetation of the Province of Trento using numerical methods, (2) to compare these results with the traditional syntaxonomic system, and (3) to examine the influence of ecological factors on variation in grassland vegetation.

CHAPTER 3: Plant diversity along an elevation gradient in alpine pastures: effects of distance from the farm centre, topography and management

The specific objective of this study was to investigate and to interpret the patterns of species richness and species composition in pastures of the Southern Alps in relation to local and regional factors. We hypothesized that (1) plant diversity varies in response to topography due to the highly variable alpine environment (Sebastia 2004; Pykälä et al. 2005; Bennie et al. 2006), and (2) variation in species composition and species richness depends strongly not only on grazing spatial gradient from the centres of the farms to the surrounding vegetation, but also on spatial distribution of the management practices within the study region (Vandvik 2002a, 2002b, 2004; Whitte et al. 2004; Klimek et al. 2007).

CHAPTER 4: Additive partitioning of plant diversity and functional diversity with respect to grassland management regime, fertilisation and abiotic factors

In this study, we collected plant species data in 24 summer farms of Province of Trento along an elevation gradient. Simpson index of diversity and functional diversity, measured as functional dispersion (Labertè and Legendre 2010), were quantified for each plot and farm. To gain insight into the processes that may affect species diversity and functional diversity in alpine pastures, the observed local patterns of additive species diversity components (α-, β-, γ-) were analysed with respect to altitude, landscape, topographic hetereogeneity, bedrock type and grazing intensity.

Study area

The study area was the Trento Province (north-eastern Italy), an area of 6207 km^2 (World Geodetic System 1984: 45°43.8'–46°28.3' N, 10°31.9'–11°53.4' E) on the southern border of the European Alps (Fig. 1.1). The elevation range varies from 66 m (Lake Garda) to 3769 m a.s.l. (Mount Cevedale). The local climate depends primarily on altitude, and only secondarily on latitude, varying from sub-mediterranean conditions in the southern and central parts to continental conditions in the inner valleys. The annual rainfall averages c. 1000 mm year^{-1} and the annual mean temperature is c. 6.5°C. The geology was heterogeneous with calcareous, siliceous bedrock and mixed sediments.

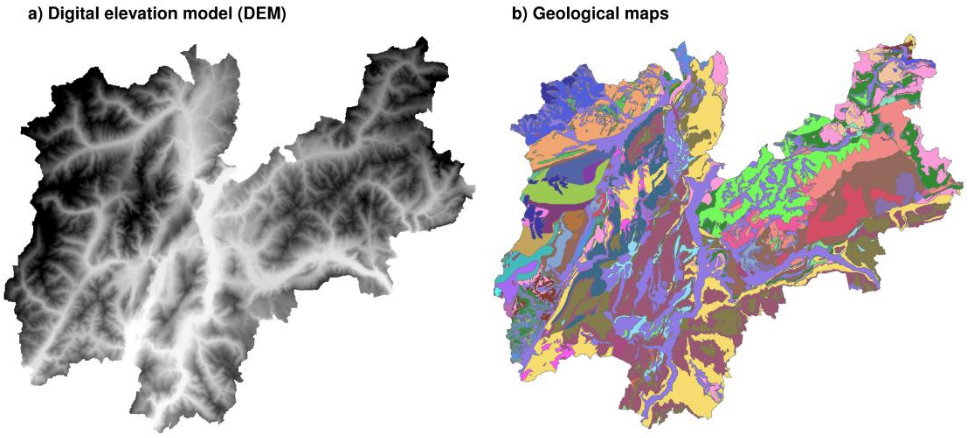


Fig. 1.1 Digital elevation model (DEM, cell size 25 × 25 m) and geological maps of Province of Trento (NE Italy - World Geodetic System 1984: 45°43.8'–46°28.3' N, 10°31.9'–11°53.4' E). Further explanations of geological types were found in Appendix A.

In the Province of Trento, managed grasslands can be grouped into two main categories: only-cut hay meadows and only-grazed pastures; mixed management is rare. Hay meadows were located in the valley bottoms around the dwellings and along the valley slopes normally between 250 and 1300m a.s.l, while pastures were located at higher altitudes, in an agricultural landscape characterized by coniferous forests or subalpine scrublands interspersed with grazed grassland, mountain hay meadows, and natural alpine and subalpine grasslands. Traditional summer pastures are grazed for two or three months during summer, mainly by cows and sheep, which are then moved back to the bottom of the valley for the rest of the year. The pastures are manured mostly in the form of animal urine and dung, and the area around the stall and other more accessible areas are supplied with farmyard manure.

Pastures represented 61.75% of the Province of Trento, with over 90,770 ha. These vegetation formations are all located at high altitudes, normally between 1000 and 2500 m a.s.l., and they are spread over the entire surface of Trentino in different areas and valleys and are mostly public property The pastures surveyed in the Province are about 700 with a total area estimated at 51,722 ha (Fig. 1.2). Those currently grazed are about 300 to an extension of *c.* 35,000 ha.

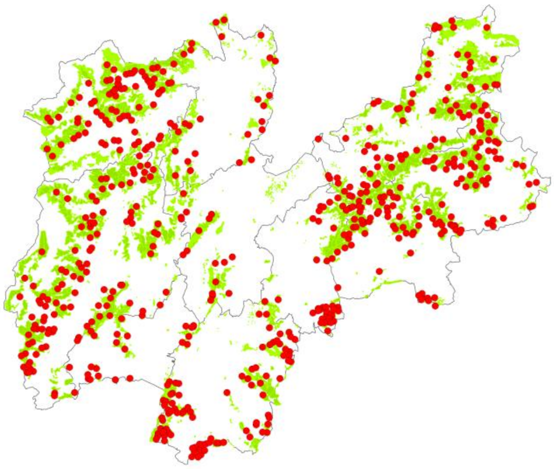


Fig. 1.2 Distribution of pastures (green area) and the summer farms ("*malghe*", red point) in Province of Trento

CHAPTER 2

CLASSIFICATION OF PASTURE COMMUNITIES IN THE PROVINCE OF TRENTO

INTRODUCTION

Phytosociologists became interested in the high-altitude vegetation since the establishment of vegetation research at the beginning of the 20th century. Several vegetation studies in the high mountains became classical in phytosociology (e.g. Rübel 1911; Braun-Blanquet & Jenny 1926). Specific conditions in the high mountains gave rise to a diverse mosaic of vegetation types, with an abundance of rare, relic and endemic taxa. Complex topography, a variety of geological bedrock and variable climatic and soil features all contribute to an exceptional variability of habitats, including refuges that provide high-mountain plants with optimal conditions.

In the nord-east Italy, detailed research dealing with vegetation of alpine pastures began in the 1950s with the studies of Gerola and Gerola (1955a, b; 1957), that recorded a number of releves from different alpine communities. CRA-ISAFA Forest and Range Management Research Institute of Villazzano (Trento) continued with this researchin in the next decades (Bezzi and Ropelato 1974-75; Bezzi and Orlandi 1978-79; Bezzi et al. 1980-82; Bezzi 1983-84; Orlandi 1983-84; Orlandi and Clementel 1989; Bezzi et al. 1993; Orlandi et al. 1997; Orlandi et al. 2000). Numerous data have been scattered in local studies, diploma and dissertation theses, unpublished research reports, etc.

Research on alpine pastures is important in many respects. From the aspect of nature protection, pastures represent a habitat for numerous plant and animal species; and, through their diversity, contribute greatly to the biodiversity and landscape value of the area. From the economic standpoint, grasslands are a source of feed for stock, a habitat for medicinal and melliferous plants. They are also capable of supporting particular dairy products, high added value, because fodder obtained from natural with unique qualities and not reproducible, capable of giving products derived valuable characteristics and identification. The management of montane and alpine pastures contributed to maintaining a diverse mosaic of open and closed areas, particularly appreciated for tourist use and protection of habitats for wildlife setting. The conservation of biodiversity (plants and animals), of ecosystem and landscape diversity and the functions of pasture vegetation is therefore closely linked with the exploitation of agro-pastoral activities and initiatives which allow rural community to preserve the territory.

Phytosociological investigation– i.e. classification of grassland communities – is important for all aspects of the study of grasslands. As in the forestry sector, also in grasslands sector some efforts have been done in recent years to characterize pasture vegetation, according to a typological approach. In the Alps, over the last years phytosociological and agronomic research on alpine pastures has been conducted through the realization of classification and interpretation manuals of pasture types, as in Veneto (Ziliotto et al. 2004) and in Piemonte (Cavallero et al. 2007). Since the pastures of the Province of Trento have not been systematically investigated for a long time, the main tasks of this work are: (1) to classify the pasture vegetation of the Province of Trento using numerical methods, (2) to compare these results with the traditional syntaxonomic system, and (3) to examine the influence of ecological factors on variation in grassland vegetation.

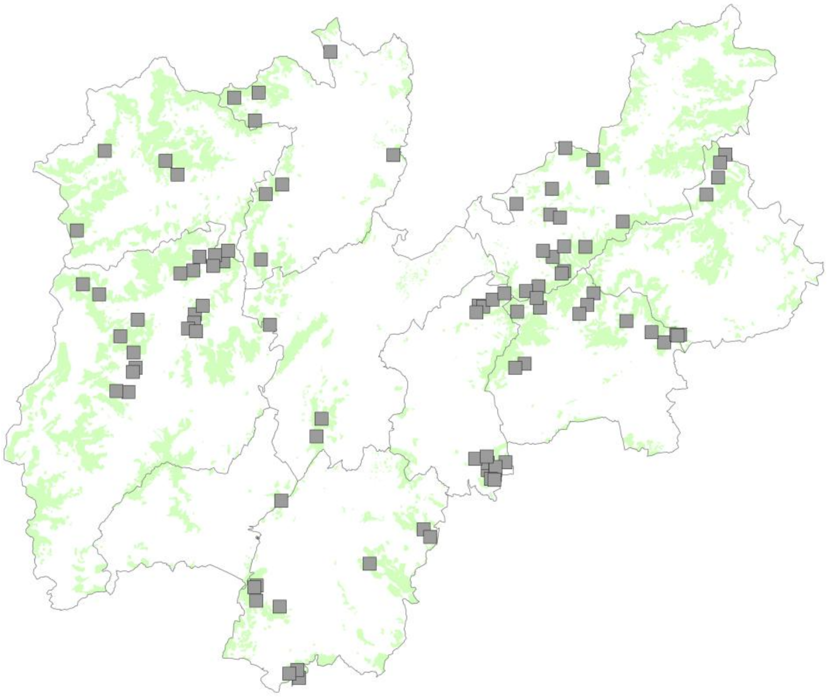


Fig. 2.1 Distribution of pastures in Province of Trento (green area) and the summer farms (“*malghe*”) sampled during the last fifty years (grey square).

MATERIAL AND METHODS

Vegetation database

The information was gathered from studies of vegetation and analysis of agronomic pastures of Trentino collected in the last fifty years by various authors of the Department of Environmental Agronomy and Crop Science - University of Padova, the CRA-MPF Forest and Range Management Research Institute (ex ISAFA) of Villazzano (TN) and the relevees from the research of Gerola and Gerola (1955a, b; 1957) (Fig. 1). In total were collected 1184 vegetation relevees. The nomenclature of taxa has been standardized using as reference Flora Alpina (Aeschimann et al. 2002). The cover data were then standardized as percentage cover of each species. Relevees where cover data followed Pignatti scale were processed in the corresponding percentages. After these standardization, were created a database where all the relevees collected in the Province of Trento during the last fifity years were stored. For each relevee all the environmental (altitude, slope, aspect, bedrock, etc.) and geographical (*x*, *y* coordinates) data availability, were gathered in the database.

Table 2.1 Summary of summer farms ("*malghe*") in the Province of Trento and samplend farms from vegetation database or new survey, grouped by geographical location and bedrock type (CAL, calcareous; ACID, acid).

	Western TN		Eastern TN		Total		Total
	CAL	ACID	CAL	ACID	CAL	ACID	
Total number of farms	204	127	86	147	290	274	564
Altitude min	630	1087	990	848	630	848	630
Altitude max	2192	2400	2200	2370	2200	2400	2400
Sampled farms from database	27	22	20	30	47	52	99
Sampled farms in 2008-2009	11	5	8	10	19	15	34
Total number of sampled farms	**39**	**27**	**28**	**40**	**67**	**67**	**134**

Sampling

The vegetation database was analyzed in a GIS environment, to examine the distribution of the summer farms ("*malghe*") and the relevees in the study area and then to determine new vegetation survey where the data availability was less. The sampling was carried out by according to geographical distribution and ecoregions (Table x). During 2008 and 2009, were sampled 18 and 16 summer farms respectively (Fig. x). The list of farms ("*malghe*") surveyd were reported in Table 2.2

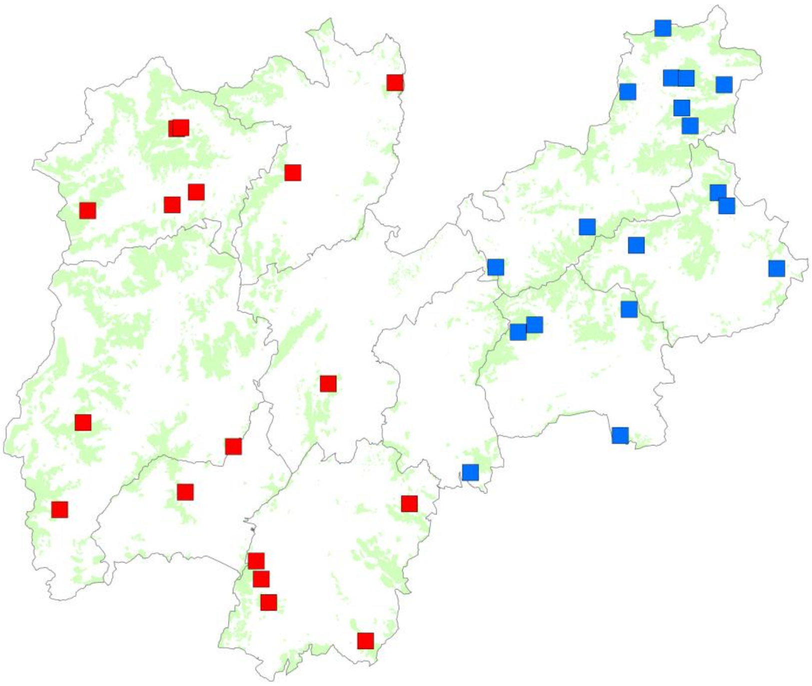


Fig. 2.2 Location of the study area showing the 34 summer farms ("*malghe*") grouped per year of survey: i) 2008 in blue; ii) 2009 in red.

In each farms, the sampling sites were selected subjectively in order to sample the major floristic variation at each farm, including heavily grazed, trampled, and manured vegetation (around the farm centre), less intensively utilized grasslands, and surrounding heaths (marginal areas). For each sites was placed a plot of 5 x 5 m; species composition was recorded in each plot using the nomenclature described by Äeschimann et al. (2004). Within each main plot, three subplots, each measuring 1 m × 1 m, were randomly located and the percentage cover of each species was estimated. A total of 323 plots were surveyd during 2008 and 2009. Each plot was georeferenced with GPS and characterized in terms of altitude, aspect and slope.

Data analysis

The vegetation database (relevees obtained from literature and relevees collectd in 2008 and in 2009) was imported into JUICE (Tichy 2002), a program for editing, classification and analysis of phytosociological tables. In order to give greater weight to the less abundant species, the percentage cover of each species have been transformed in the following ordinal scale: 1 = 1%, 2 = 2%, 3 = 3%, 4 = 4%, 5 = 5-15% , 6 = 16-25%, 7 = 26-50%, 8 = 51-75%, 9 = 76-100%. The relevees were subjected to agglomerative cluster analysis with the coefficient of Van der Maarel as a function of similarity and the minimum variance as a method of classification (Wildi and Orloci 1996). In this first analysis were identified four main groups of pastures (mesic and degraded pastures, pastures on calcareous bedrocks, pastures on siliceous bedrocks, shrubbed and reforested pastures). Subsequently, for each main main group was carried out, separately, a new cluster analysis to identify the main vegetation types. The main types of pasture have been identified with phytosociological criteria, namely according to species characteristics and differential syntaxon. A posteriori, using the Φ coefficient of association standardised to the equal group size (Tichy & Chytry 2006) by calculating fidelity of each species to each cluster in the program JUICE.The threshold value for a species to be considered as diagnostic was set to $\Phi \geq 0.30$. The final interpretation of vegetation types and the syntax names follow Mucina *et al*. (1993a, b) and Ziliotto *et al*. (2004). The results of the classification were summarized in a synoptic table. The diagnostic species were ranked by decreasing cover value.

Each pasture seems to be a uniform grassy pasture, but differences in facies patterns are clearly noted when the vegetation is investigated close up. For each main formation, was also determined a series of vegetation sub-types (e.g., dry, mesic, degraded, shrubbed). To identify the vegetation sub-types was carried out a further cluster analysis for each main types of pasture. The pasture types were also characterized by altitude distribution, slope and polar coordinate of aspect. The influence of ecological factors, explained by Ellenberg indicator (Ellenberg et al. 1991), on main formation was examined by the Principal Components Analysis (PCA) in the CANOCO 4.5 program (ter Braak & Šmilauer 2002). The proportion of each plant species was calculated to obtain an overall grazing quality score, i.e. a forage value, following the classification of Knapp (1971) and Stählin (1971).

Table 2.2 Sampled summer farms ("*malghe*") in 2008 and in 2009.

Summer farms	Altitude	Bedrock	N. of relevees
2008			**177**
Campocapra di sopra	1358	CAL	11
Contrin	2055	CAL	9
Dal Coston	1839	ACID	9
Fosse	1880	CAL	9
Fossernica di dentro	1777	ACID	10
Fossetta	1560	ACID	9
Fregio	1532	ACID	8
Giumela alta	2250	ACID	9
Giumela bassa	1950	ACID	9
Millegrobbe di sotto	1426	CAL	13
Monzoni	1862	CAL	9
Pala	1900	CAL	9
Sarcine	1820	ACID	9
Sasso Piatto	2248	ACID	9
Sette Selle	1906	ACID	9
Toazzo	1468	ACID	9
Tolva	1563	ACID	9
Vael	2050	CAL	9
Vallazza	1935	ACID	9
2009			**146**
Avalina	1950	CAL	11
Bondolo	1889	CAL	9
Brigolina	973	CAL	9
Bronzolo	2020	ACID	6
Campo	1671	CAL	11
Di Fondo	1451	CAL	11
Di Valpiana	1260	ACID	9
Di Vigo	1087	CAL	9
Fazzon	1511	ACID	8
Grassi	1048	CAL	8
Mondent	1902	ACID	9
Mortigola	1157	CAL	9
Strino	1979	ACID	9
Susine	1337	CAL	9
Tuenna	1037	CAL	8
Valle Orsara	1488	CAL	11
		TOT.	**323**

RESULTS

The cluster analysis identified four main groups of pastures:

1) Mesic and degraded pastures
2) Pastures on calcareous bedrocks
3) Pastures on siliceous bedrocks
4) Shrubbed and reforested pastures

Subsequently, for each main main group was carried out, separately, a new cluster analysis to identify the main vegetation types. In the study area were found the following main types of pasture:

1) Mesic and degrade pastures
    - *a) Lolio perennis-Cynosuretum*
    - *b) Festuco commutatae-Cynosuretum*
    - *c) Poion alpinae*
    - d) Grasslands dominated by tall-growing grasses
    - e) Overgrazed and degraded pastures
    - *f) Rumicetum alpini*
2) Pastures on calcareous bedrocks
    - *a) Bromion erecti*
    - *b) Seslerio-Caricetum sempervirentis*
    - *c) Caricetalia firmae*
3) Pastures on siliceous bedrocks
    - *a) Homogyno alpinae-Nardetum*
    - *b) Sieversio-Nardetum strictae*
    - *c) Festucetum halleri*
    - *d) Festucion varie*
    - *e) Loiseleurio-Vaccinion*

   f) Fens

4) Shrubbed and reforested pastures
   - *a) Rhododendretum ferruginei*
   - *b) Alnetum viridis*
   - *c) Erico-Pinion mugo*
   - *d) Larici-Pinetum cembrae*

1. *Lolio perennis-Cynosuretum*

Phytosociological nomenclature: *Lolio perennis-Cynosuretum* Br.-Bl. et De Leueuw 1936.

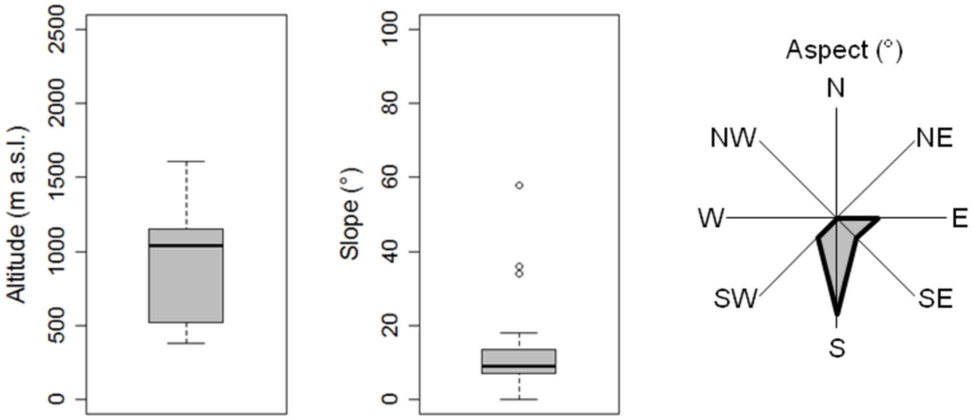
EUNIS classification : E2.1

Corine classification : 38.11

Topography : Altitude (500-1200 m a.s.l.); Slope (7-13°); Aspect (SE-SW).

Bedrock:

Fig. 2.1 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	Cov	Freq
Trifolium repens repens	19.8	95
Lolium perenne	15.5	100
Dactylis glomerata glomerata	8.2	84
Poa pratensis	4.7	47
Plantago major	4.4	63
Digitaria sanguinalis	3.6	21
Taraxacum officinale	3.3	89
Festuca pratensis pratensis	3	47
Poa annua	2.9	32
Achillea millefolium millefolium	2.2	84
Trifolium pratense pratense	2.2	63

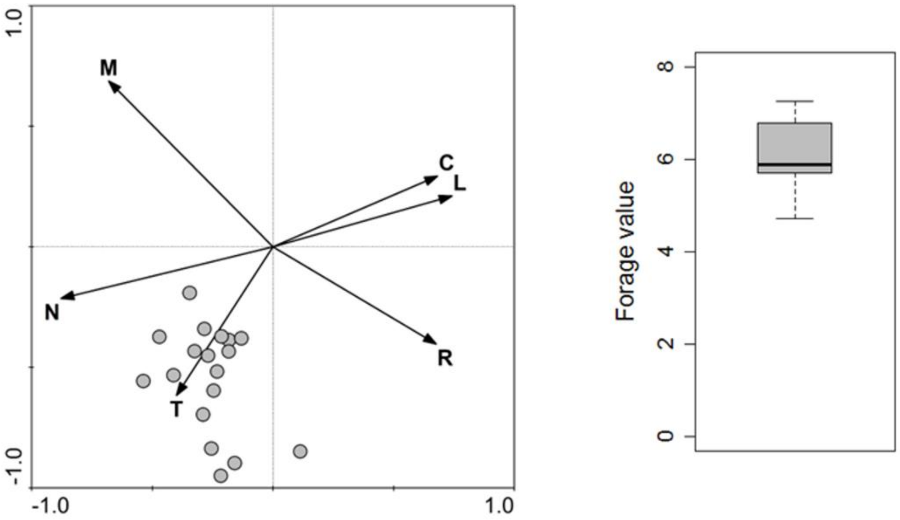
Species	Cov	Freq
Vicia sativa sativa	2.0	5
Rumex obtusifolius obtusifolius	1.9	32
Trisetum flavescens	1.8	53
Carum carvi	1.5	47
Phleum pratense	1.5	37
Cynosurus cristatus	1.4	32
Poa trivialis trivialis	1.3	37
Agrostis capillaris	1.2	42
Ranunculus acris acris	1.2	58
Plantago lanceolata	1.1	47
Rumex acetosa	1.1	37

Characteristic species: *Lolium perenne, Poa pratensis, Trifolium repens, Taraxacum officinale, Cynosurus cristatus, Trisetum flavescens*.

Ecological indicator value: C, continentality (2.4); L, light (3.7); M, moisture (2.3); N, nutrient (2.8); R, reaction (2.4); T, temperature (2.6).

Forage value: 5.5-7.0

Fig. 2.2 PCA ordination of ecological indicator value and boxplot of forage value.

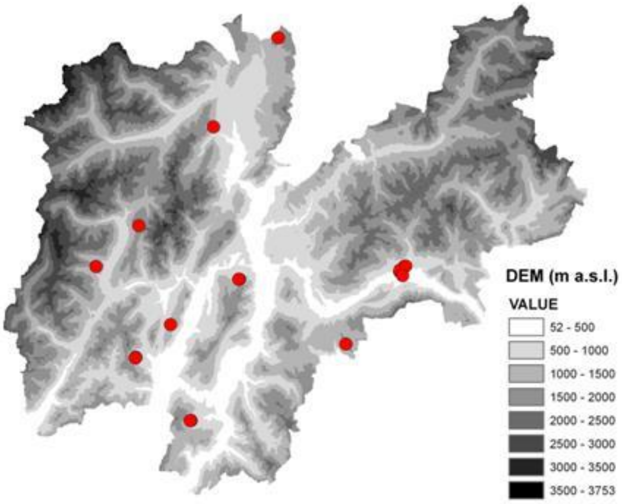


Distribution in the farm: *Lolio-cynosuretum* grasslands are placed in the more intensively grazed and flat pastures located close to the farm.

Grazing season: from mid May to late September (105-135 days).

Average stock rate: 1.8-2.7 LU ha^{-1}.

Fig. 2.3 Location of *Lolio-cynosuretum* grasslands within the Province of Trento.



2. *Festuco commutatae-Cynosuretum*

Phytosociological nomenclature: *Festuco commutatae-Cynosuretum* R. Tx. ex Büker 1942.

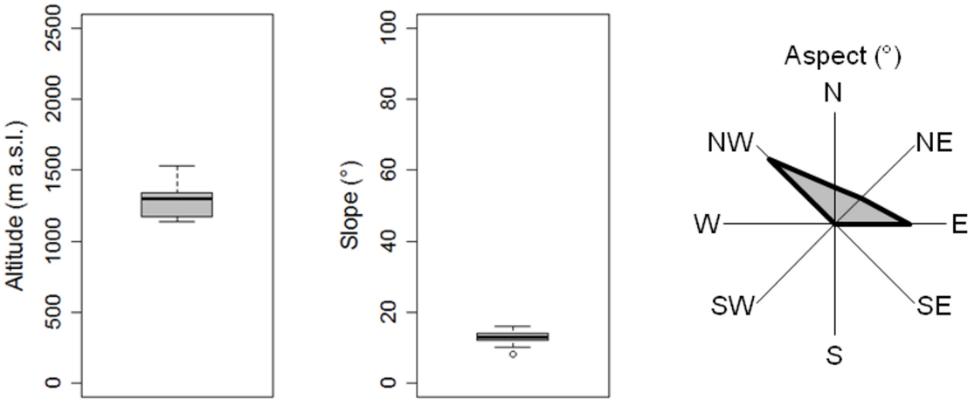
EUNIS classification : E2.1

Corine classification : 38.11

Topography : Altitude (1200-1400 m a.s.l.); Slope (12-15°); Aspect (NW-E).

Bedrock:

Fig. 2.4 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

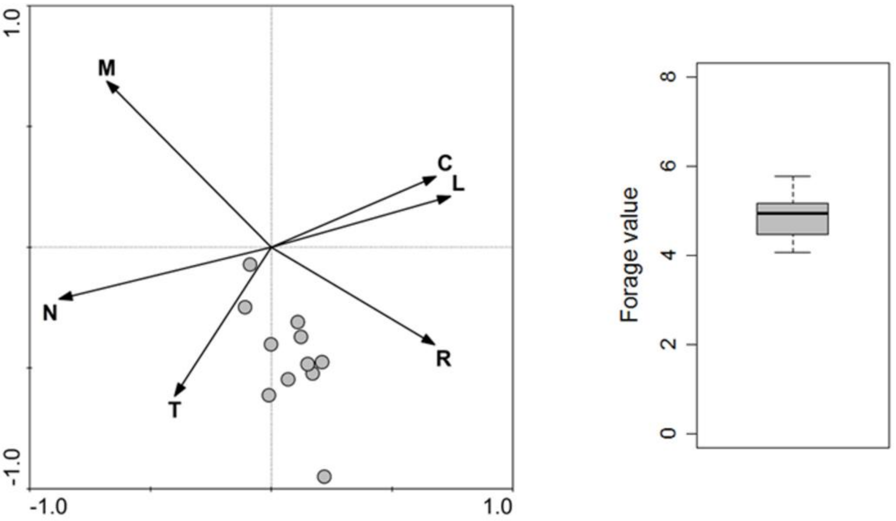
Species	Cov	Freq
Festuca rubra agg.	20.7	100
Trifolium pratense	7.7	100
Trifolium repens	7.2	100
Cynosurus cristatus	6.5	91
Agrostis capillaris	5.5	91
Achillea millefolium	2.8	100
Lotus corniculatus	2.8	91
Ranunculus acris	2.7	91
Alchemilla vulgaris	2.5	82
Dactylis glomerata	2.5	64
Trisetum flavescens	2.5	82
Plantago lanceolata	2.3	55
Plantago media	2.3	73
Leontodon hispidus	2.2	73
Prunella vulgaris	2	73
Anthoxanthum odoratum	1.9	64
Carum carvi	1.9	64
Veratrum album	1.8	45
Leucanthemum vulgare	1.7	73
Stellaria graminea	1.7	73
Galium verum	1.6	55
Centaurea nigrescens	1.5	64
Crepis capillaris	1.5	55
Salvia pratensis	1.5	27
Briza media	1.4	45
Festuca pratensis	1.4	45
Knautia arvensis	1.4	45
Polygonum bistorta	1.0	55

Characteristic species: *Festuca rubra* agg., *Trifolium repens, Cynosurus cristatus, Poa pratensis, Anthoxanthum odoratum*, *Dactylis glomerata, Trifolium pratense, Lotus corniculatus, Leontodon hispidus, Alchemilla vulgaris, Carum carvi.*

Ecological indicator value: C, continentality (2.5); L, light (3.7); M, moisture (2.1); N, nutrient (2.4); R, reaction (2.4); T, temperature (2.5).

Forage value: 4.5-5.2

Fig. 2.5 PCA ordination of ecological indicator value and boxplot of forage value.

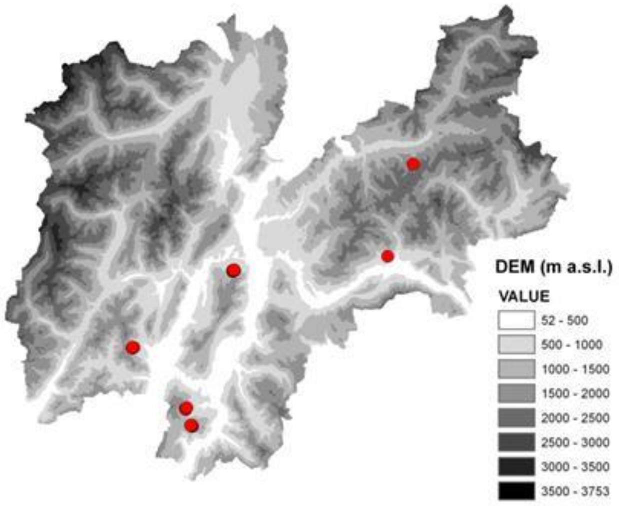


Distribution in the farm: *Festuco-cynosuretum* grasslands are placed over large areas with reduced slope and also far from the farm centre.

Grazing season: from mid May to late September (105-135 days).

Average stock rate: 0.9-1.9 LU ha^{-1}.

Fig. 2.6 Location of *Festuco-cynosuretum* grasslands within the Province of Trento.



FACIES

1.1 Dry facies

Characteristic species: *Bromus erectus, Helictotrichon pubescens, Briza media, Brachypodium pinnatum, Plantago media*.

1.2 Mountain – subalpine facies

Characteristic species: *Poa alpina, Phleum rhaeticum, Lotus alpinus.*

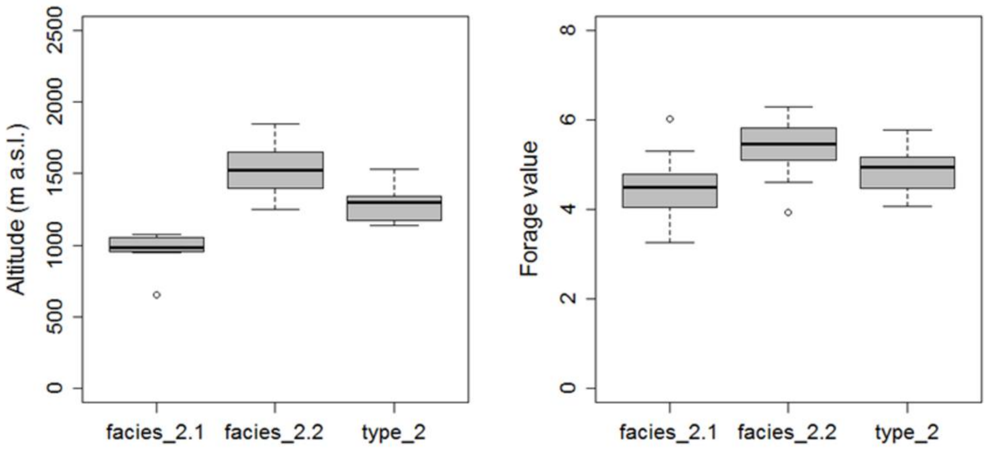
2.1 Dry

Species	Cov
Festuca gr. rubra	14.2
Anthoxanthum odoratum	9.3
Cynosurus cristatus	8.9
Trifolium pratense	5.1
Agrostis capillaris	3.1
Rhinanthus alectorolophus	2.9
Trisetum flavescens	2.9
Dactylis glomerata	2.6
Plantago lanceolata	2.6
Helictotrichon pubescens	2.4
Briza media	2.2
Leontodon hispidus	2.2
Achillea millefolium	2.1
Plantago media	1.9
Bromus erectus	1.8

2.2 Mountain - subalpine

Species	Cov
Festuca rubra agg.	17.7
Trifolium repens	9.6
Poa alpina	7.8
Alchemilla vulgaris	7.6
Phleum rhaeticum	7.3
Agrostis capillaris	6.9
Trifolium pratense	6.2
Deschampsia cespitosa	4.2
Achillea millefolium	3.7
Ranunculus acris acris	3.3
Carum carvi	2.6
Leontodon hispidus	2.4
Poa pratensis	2.0
Lotus alpinus	1.6
Dactylis glomerata	1.4

Fig. 2.7 Difference in altitude and in forage value between facies (2.1, xeric; 2.2, mountain – subalpine) and *Festuco-cynosuretum* type (2).



3. *Poion alpinae*

Phytosociological nomenclature: *Poion alpinae* Oberd. 1950

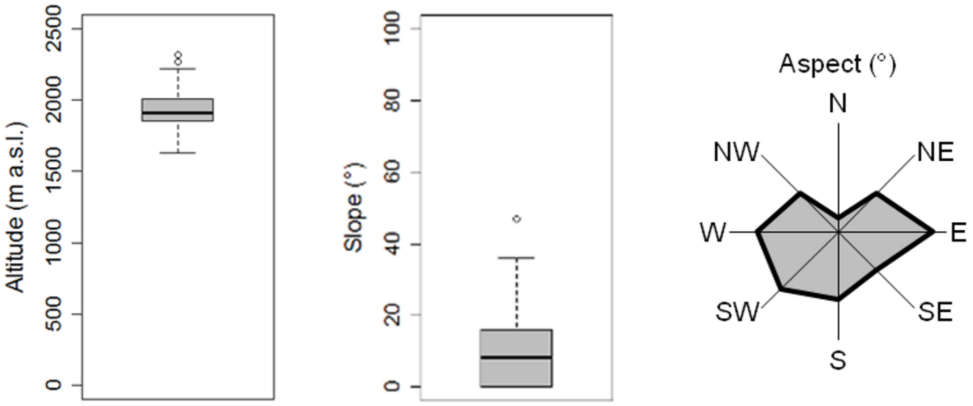
EUNIS classification : E4.5

Corine classification : 38.3

Topography : Altitude (1850-2000 m a.s.l.); Slope (0-16°); Aspect (E-SW).

Bedrock:

Fig. 2.8 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	Cov	Freq
Festuca rubra agg.	13.3	96
Poa alpina	8.3	94
Alchemilla vulgaris	7.1	76
Trifolium repens	7.1	87
Agrostis capillaris	6.9	85
Phleum rhaeticum	6.1	80
Deschampsia cespitosa	4.6	90
Trifolium pratense	3.4	69
Achillea millefolium	2.9	70
Anthoxanthum odoratum	2.7	75
Geum montanum	2.4	39
Ranunculus acris	2.3	52
Carum carvi	2.2	76
Ranunculus montanus	1.9	55

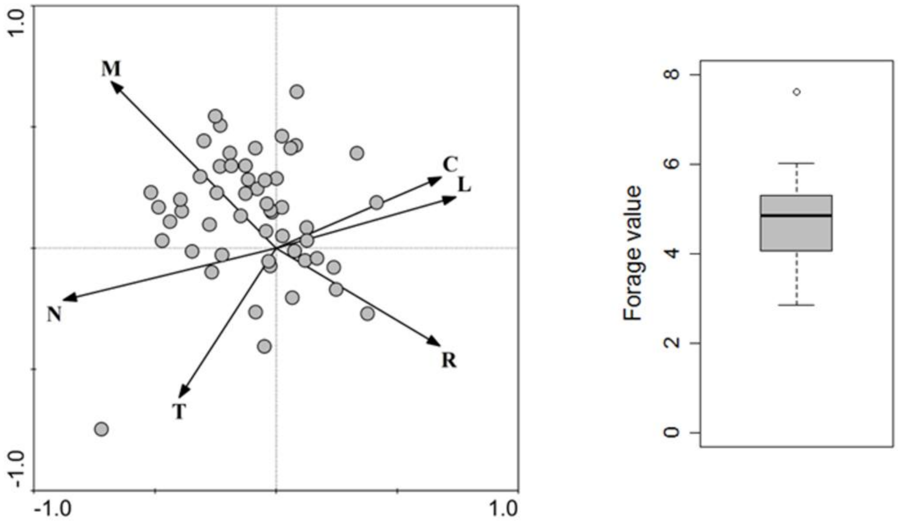
Species	Cov	Freq
Leontodon hispidus	1.8	57
Nardus stricta	1.7	54
Leontodon autumnalis	1.4	42
Lotus corniculatus	1.4	40
Potentilla aurea	1.4	37
Potentilla erecta	1.4	34
Taraxacum officinale	1.4	36
Veronica chamaedrys	1.2	43
Luzula campestris	1.1	49
Trifolium badium	1.1	40
Crepis aurea	1.0	50

Characteristic species: *Festuca rubra* agg., *Poa alpina, Phleum rhaeticum, Agrostis capillaris, Trifolium repens, Alchemilla vulgaris, Anthoxanthum odoratum, Leontodon hispidus, Potentilla aurea, Ranunculus acris, Ranunculus montanus, Trifolium badium, Crepis aurea, Lotus alpinus.*

Ecological indicator value: C, continentality (2.6); L, light (3.6); M, moisture (2.6); N, nutrient (2.5); R, reaction (2.3); T, temperature (2.4).

Forage value: 4.1-5.3

Fig. 2.9 PCA ordination of ecological indicator value and boxplot of forage value.

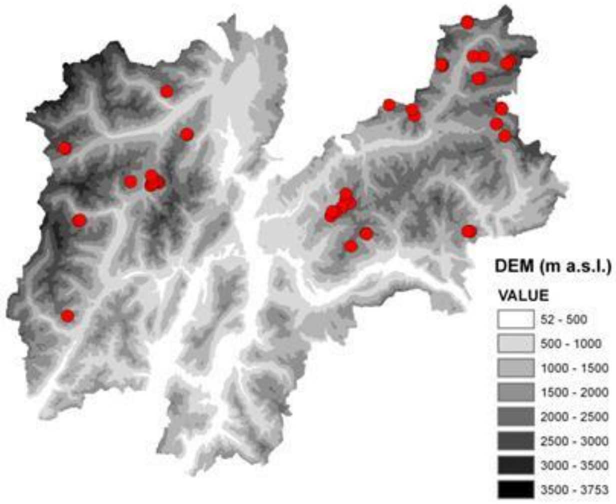


Distribution in the farm: *Poion alpinae* grasslands are usually placed over areas with low extension and close to the farm.

Grazing season: from mid-late June to early September (60-75 days).

Average stock rate: 1.3-2.6 LU ha^{-1}.

Fig.2.10 Location of *Poion alpinae* grasslands within the Province of Trento.



FACIES

1.3 Mountain facies

Characteristic species: *Lotus corniculatus***,** *Poa pratensis, Taraxacum officinale, Stellaria graminea, Veronica chamaedrys.*

1.4 On calcareous bedrock facies

Characteristic species: *Horminum pyrenaicum, Trifolium pratense nivale, Galium anisophyllon.*

1.5 Acidophillus facies

Characteristic species: *Nardus stricta, Geum montanum, Leontodon helveticu, Luzula campestris.*

1.6 Degraded facies

Characteristic species: *Deschampsia cespitosa, Cirsium spinosissimum.*

3.1 Mountain

Species	Cov
Poa alpina	8.4
Festuca rubra agg.	7.8
Trifolium repens repens	6.8
Phleum rhaeticum	5.9
Deschampsia cespitosa	5.5
Achillea millefolium	4.8
Agrostis capillaris	4.4
Alchemilla vulgaris	3.4
Lotus corniculatus	2.7
Ranunculus acris	2.5
Trifolium pratense	2.5
Taraxacum officinale	2.3
Veronica chamaedrys	2.2
Poa pratensis	2.0
Stellaria graminea	1.1

3.2 On calcareous bedrock

Species	Cov
Festuca rubra agg.	15.9
Poa alpina	8.8
Horminum pyrenaicum	6.2
Lotus alpinus	4.3
Anthoxanthum odoratum	3.8
Crepis aurea	3.6
Homogyne alpina	3.1
Thymus serpyllum agg.	2.8
Alchemilla vulgaris	2.7
Phleum rhaeticum	2.7
Leontodon hispidus	2.4
Trifolium pratense nivale	2.4
Galium anisophyllon	2.0
Trifolium badium	1.0
Ranunculus montanus	1.0

3.3 Acidophilus

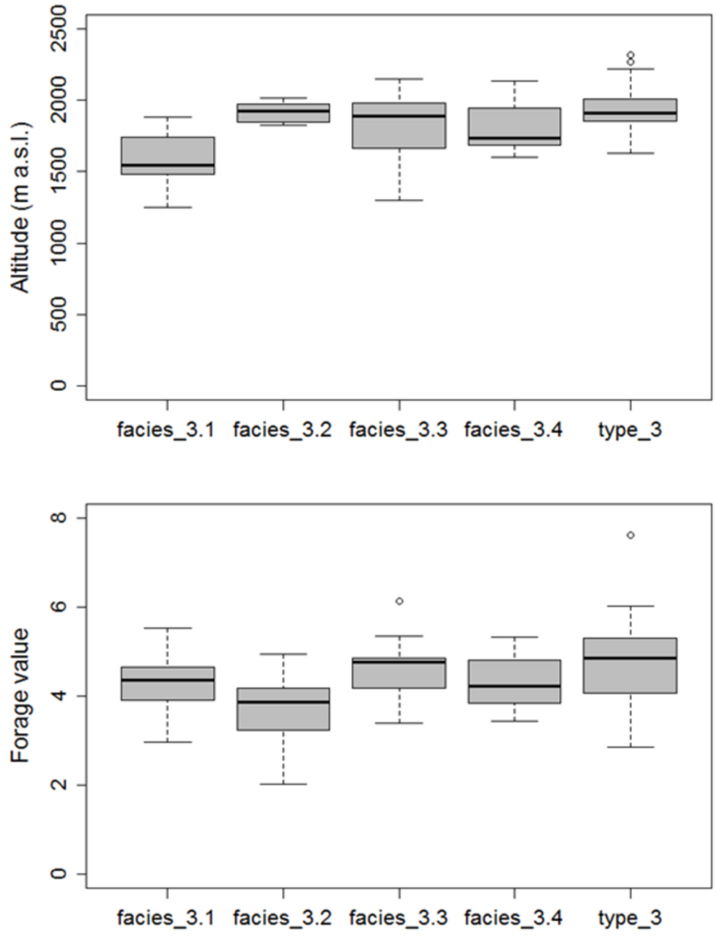
Species	Cov
Festuca rubra agg.	17.3
Alchemilla vulgaris	11.0
Poa alpina	10.8
Nardus stricta	8.7
Trifolium pratense nivale	6.7
Trifolium repens	6.4
Ranunculus montanus	4.3
Phleum rhaeticum	4.2
Agrostis capillaris	2.9

3.4 Degraded

Species	Cov
Deschampsia cespitosa	33.5
Festuca rubra agg.	12.1
Agrostis capillaris	9.2
Phleum rhaeticum	8.2
Poa alpina	5.7
Trifolium repens	5.3
Nardus stricta	4.6
Carex leporina	2.3
Cirsium spinosissimum	2.0

Geum montanum	2.5	*Anthoxanthum odoratum*	1.6
Achillea millefolium	2.3	*Achillea millefolium*	1.5
Anthoxanthum odoratum	2.3	*Ranunculus montanus*	1.4
Leontodon helveticus	2.0	*Alchemilla vulgaris*	1.3
Hieracium pilosella	1.9	*Festuca pratensis*	1.3
Luzula campestris	1.7	*Agrostis stolonifera*	1.2

Fig. 2.11 Difference in altitude and in forage value between facies (3.1, mountain; 3.2, on calcareous bedrock; 3.3, acidophilus; 3.4, degraded) and *Poion alpinae* type (3).



4. Grasslands dominated by tall-growing grasses

Phytosociological nomenclature: agg. a *Poa trivialis*

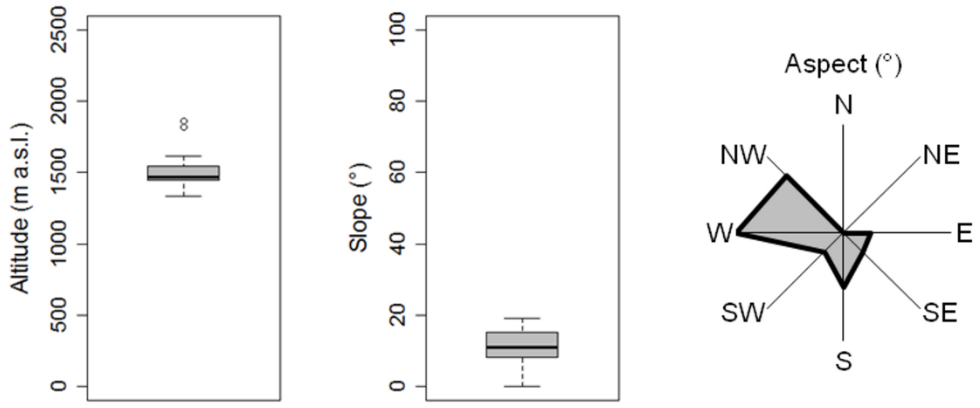
EUNIS classification : E2.2

Corine classification : 38.2

Topography : Altitude (1450-1550 m a.s.l.); Slope (8-15°); Aspect (SE-NW).

Bedrock:

Fig. 2.12 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	Cov	Freq
Dactylis glomerata	11.7	100
Festuca pratensis	7.1	71
Festuca rubra agg.	6	86
Poa trivialis trivialis	4.9	29
Poa pratensis	4.4	79
Phleum pratense	4.2	50
Trisetum flavescens	4.1	71
Carum carvi	3.3	93
Senecio alpinus	3.3	36
Urtica dioica	3.3	36
Trifolium repens	3.2	57
Achillea millefolium	3.1	100
Alchemilla vulgaris	3.1	86
Trifolium pratense	3	93

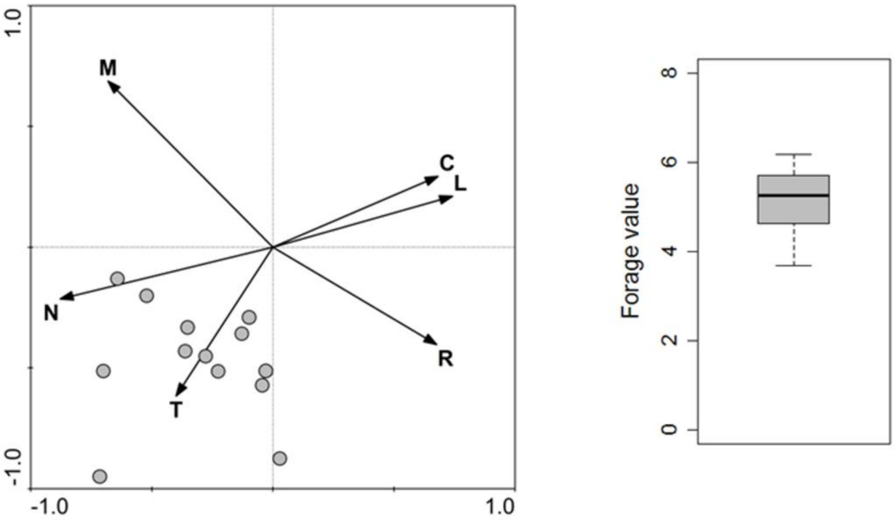
Species	Cov	Freq
Carduus nutans	1.3	43
Cirsium eriophorum	1.1	36
Geranium phaeum	1.1	21
Rumex acetosa	1.1	43

Characteristic species: *Dactylis glomerata, Festuca pratensis, Poa trivialis, Poa pratensis, Phleum pratense, Trisetum flavescens, Festuca rubra agg.*

Ecological indicator value: C, continentality (2.5); L, light (3.6); M, moisture (2.4); N, nutrient (2.8); R, reaction (2.5); T, temperature (2.4).

Forage value: 4.6-5.7

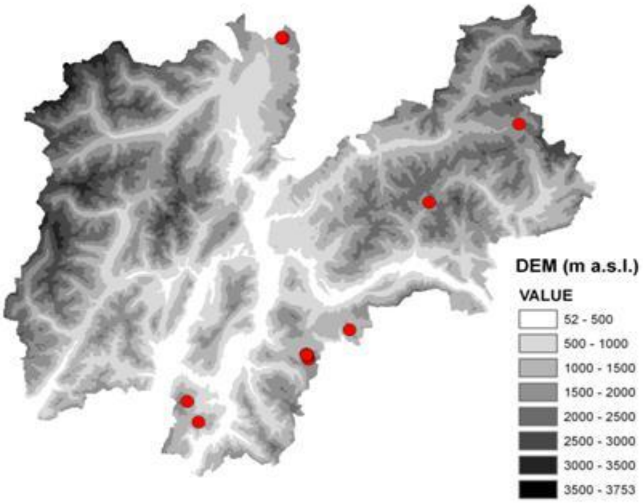
Fig. 2.13 PCA ordination of ecological indicator value and boxplot of forage value.



Distribution in the farm: Grasslands dominated by tall-growing grasses are usually placed close to the farm centre, where there is a high level of nitrogen supply.

Management: it is better to graze this pastures early, otherwise it is possible to manage by mowing

Fig. 2.14 Location of grasslands dominated by tall-growing grasses within the Province of Trento.



5. Overgrazed and degraded pastures

Phytosociological nomenclature: agg. a *Poa trivialis*

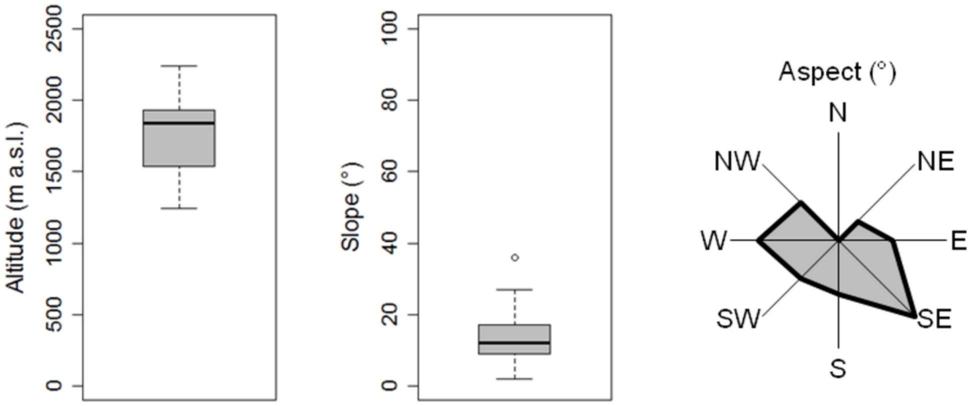
EUNIS classification : E2.2

Corine classification : 38.2

Topography : Altitude (1550-1900 m a.s.l.); Slope (9-17°); Aspect (E-W).

Bedrock:

Fig. 2.15 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	**Cov**	**Freq**
Deschampsia cespitosa	16.5	94
Rumex alpinus	12.8	87
Alchemilla vulgaris	8.7	100
Senecio alpinus	7	52
Trifolium repens	5.5	84
Poa trivialis	5.4	48
Festuca rubra agg.	4.7	77
Poa pratensis	4.5	48
Urtica dioica	3.3	74
Ranunculus acris	2.8	77
Trifolium pratense	2.8	74
Agrostis capillaris	2.5	71
Phleum rhaeticum	2.5	61
Plantago major	2.5	71

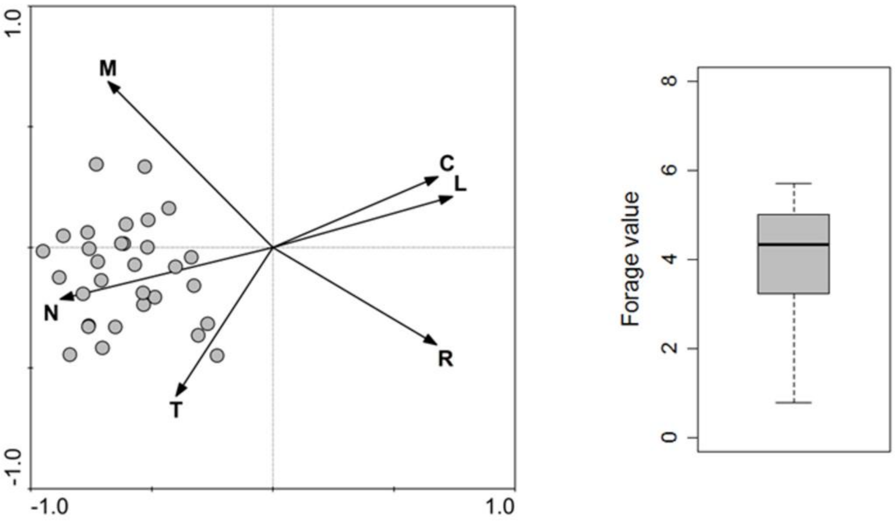
Species	**Cov**	**Freq**
Carum carvi	2.4	68
Phleum pratense	2.2	42
Poa alpina	2.2	74
Achillea millefolium	1.9	74
Poa supina	1.9	29
Dactylis glomerata	1.7	29
Rumex alpestris	1.3	35
Festuca pratensis	1.0	6.0

Characteristic species: *Deschampsia cespitosa*, *Rumex alpinus*, *Senecio alpinus*, *Trifolium repens*, *Poa trivialis*, *Urtica dioica*, *Plantago major*, *Poa supina* .

Ecological indicator value: C, continentality (2.4); L, light (3.5); M, moisture (2.7); N, nutrient (3.0); R, reaction (2.4); T, temperature (2.2).

Forage value: 4.6-5.7

Fig. 2.16 PCA ordination of ecological indicator value and boxplot of forage value.

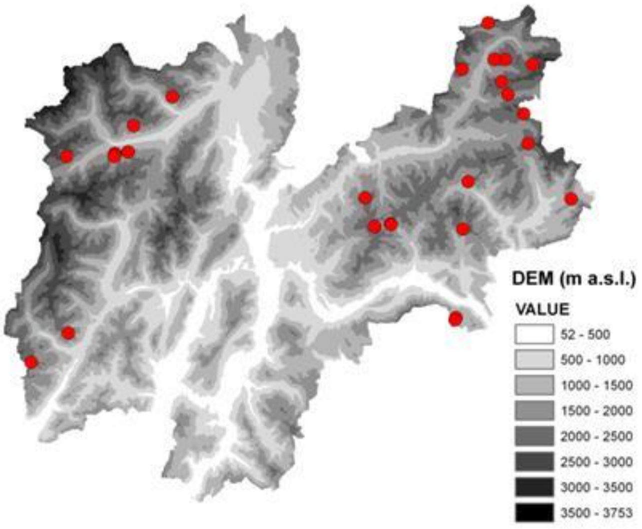


Distribution in the farm: Overgrazed and degraded pastures are usually placed close to the farm centre or in the resting area.

Grazing season: from mid-late June to early September (60-75 days).

Average stock rate: 0.6-1.8 LU ha^{-1}.

Fig.2.17 Location of overgrazed and degraded pastures within the Province of Trento.



6. *Rumicetum alpini*

Phytosociological nomenclature: *Rumicetum alpini* Beger 1922

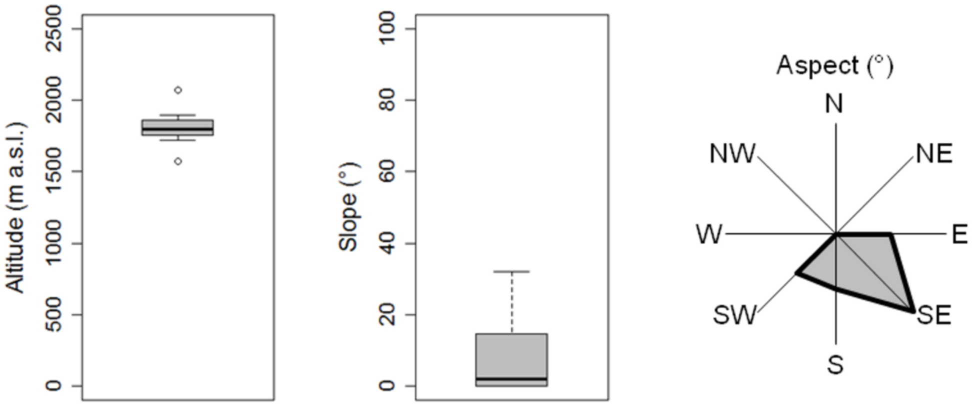
EUNIS classification : E5.58

Corine classification : 37.88

Topography : Altitude (1750-1850 m a.s.l.); Slope (0-8°); Aspect (E-SW).

Bedrock:

Fig. 2.18 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

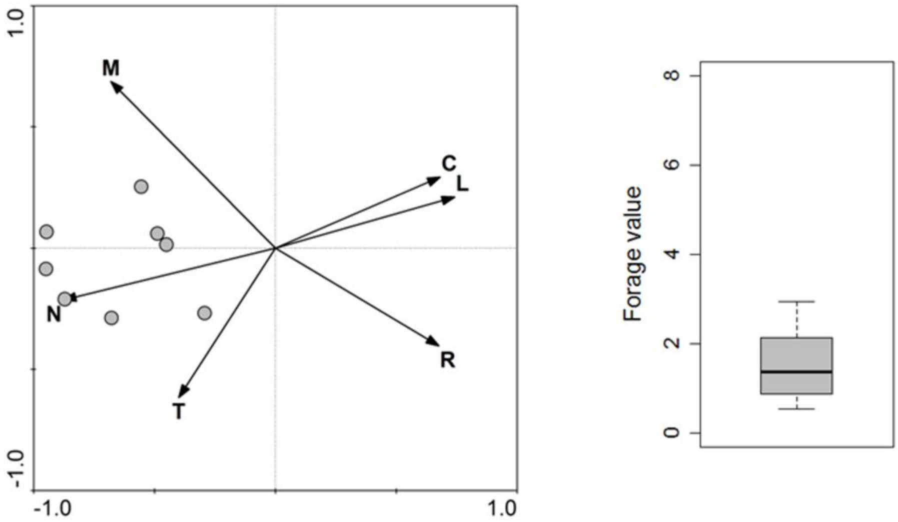
Species	**Cov**	**Freq**
Rumex alpinus	35.0	100
Senecio alpinus	20.7	100
Urtica dioica	9.8	100
Stellaria nemorum	7.6	44
Alchemilla vulgaris	7.1	78
Deschampsia cespitosa	6.9	100
Senecio cacaliaster	4.1	67
Geum rivale	2.2	11
Festuca gr. rubra	1.6	44
Poa alpina	1.0	33
Rumex alpestris	1.0	22
Trifolium pratense	1.0	33
Trifolium repens	1.0	22

Characteristic species: *Rumex alpinus, Senecio alpinus, Urtica dioica, Stellaria nemorum.*

Ecological indicator value: C, continentality (2.3); L, light (3.4); M, moisture (2.8); N, nutrient (3.3); R, reaction (2.5); T, temperature (2.2).

Forage value: 0.9-1.9

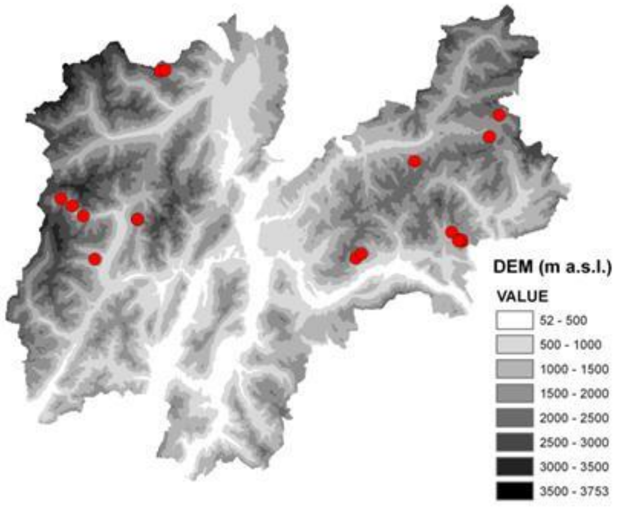
Fig. 2.19 PCA ordination of ecological indicator value and boxplot of forage value.



Distribution in the farm: *Rumicetum alpini* is usually placed close to the farm centre, to the resting area, to the pond water or the dunghill where there is manure or sewage sludge accumulation. *Rumex alpinus* is usually a strong dominant in its stands. Its successful spreading is enhanced by effective suppression of other species by shading and by fast occupation of both above- and below-ground space.

Management: *Rumex alpinus* is avoided by cattle; however, it is eaten by goats.

Fig. 2.20 Location of *Rumicetum alpini* within the Province of Trento.



7. *Bromion erecti*

Phytosociological nomenclature: *Bromion erecti Koch 1926*

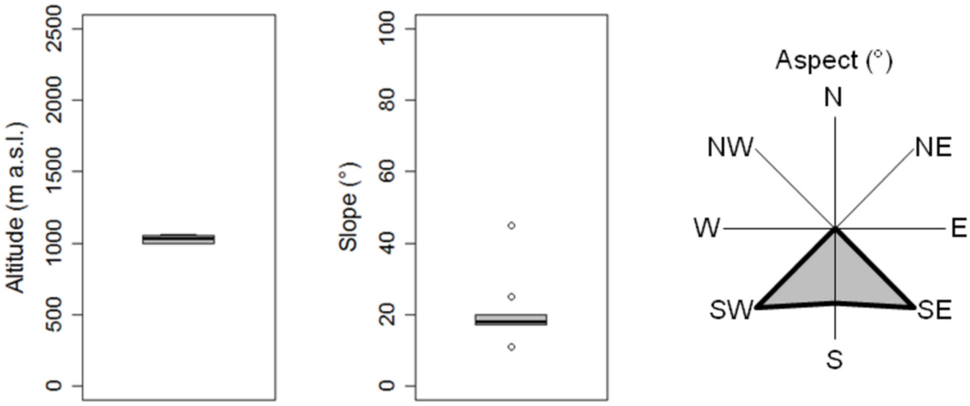
EUNIS classification : E1.26

Corine classification : 34.322

Topography : Altitude (1000-1100 m a.s.l.); Slope (17-20°); Aspect (SE-SW).

Bedrock:

Fig. 2.21 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	**Cov**	**Freq**
Bromus erectus	21.7	100
Festuca rupicola	6.9	89
Trifolium montanum	5.1	100
Chamaecytisus hirsutus	4.7	22
Salvia pratensis	4.3	89
Festuca rubra agg.	3.7	67
Achillea millefolium	3.6	78
Koeleria pyramidata	3.4	89
Helianthemum nummularium	3.2	56
Plantago media	2.9	78
Lotus corniculatus	2.8	89
Brachypodium pinnatum	2.7	56
Briza media	2.2	56
Plantago lanceolata	2.2	78

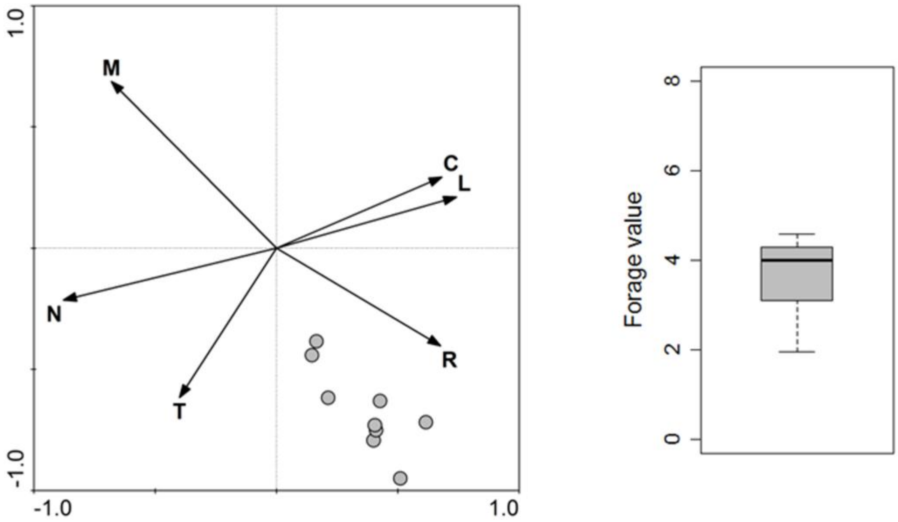
Species	**Cov**	**Freq**
Galium verum	2	67
Centaurea scabiosa	1.9	67
Dactylis glomerata	1.8	78
Carex caryophyllea	1.7	56
Leontodon hispidus	1.7	67
Medicago lupulina	1.6	67
Centaurea jacea gaudinii	1.3	44
Trifolium pratense	1.3	44
Filipendula vulgaris	1.1	33
Helianthemum canum	1.1	33
Thymus serpyllum agg.	1.1	33
Agrostis capillaris	1	33
Anthoxanthum odoratum	1	33
Prunella laciniata	1	33

Characteristic species: *Bromus erectus, Festuca rupicola, Koeleria pyramidata, Brachypodium pinnatum, Trifolium montanum, Galium verum, Helianthemum nummularium, Thymus serpyllum agg.*

Ecological indicator value: C, continentality (2.4); L, light (3.7); M, moisture (1.6); N, nutrient (1.9); R, reaction (2.4); T, temperature (2.5).

Forage value: 3.1-4.3

Fig. 2.22 PCA ordination of ecological indicator value and boxplot of forage value.

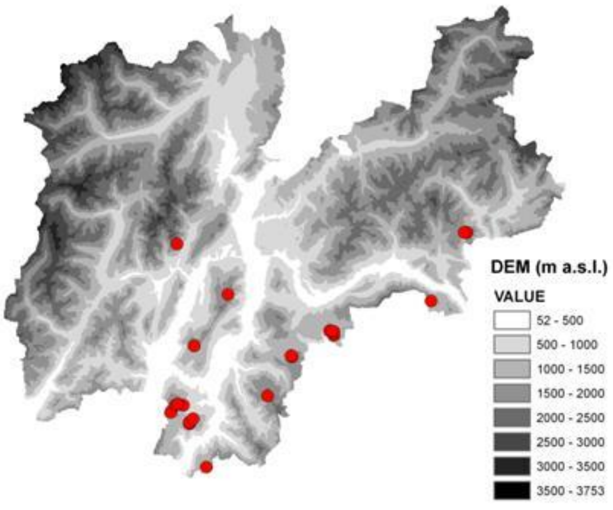


Distribution in the farm: *Mesobromion* grasslands are usually placed both close to the farm (mostly mesic facies) that far from the farm centre (mostly dry facies). This pastures are often placed on slope side and on calcareous bedrock.

Grazing season: from mid-May to mid September.

Average stock rate: 0.4-1.5 LU ha^{-1}.

Fig. 2.23 Location of *Mesobromion* grasslands within the Province of Trento.



FACIES

1.7 Mesic facies

Characteristic species: *Festuca rubra* agg.**,** *Alchemilla vulgaris, Lotus corniculatus, Carum carvi, Dactylis glomerata, Leontodon hispidus, Trifolium pratense, Trifolium repens.*

1.8 Mountain facies

Characteristic species: *Festuca rupicola, Anthyllis vulneraria, Acinos alpinus, Ranunculus montanus.*

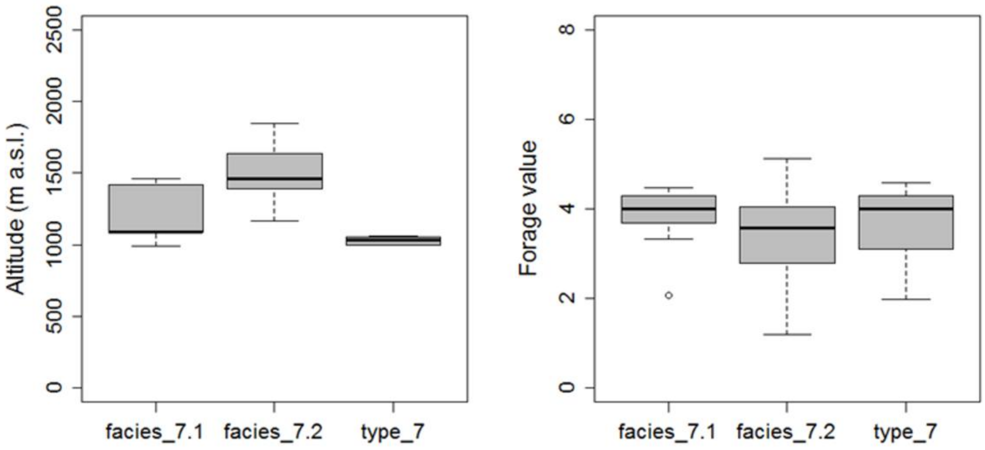
7.1 Mesic

Species	**Cov**
Bromus erectus	10.4
Festuca rubra agg.	9.2
Festuca rupicola	4.3
Koeleria pyramidata	3.1
Trifolium montanum	2.8
Alchemilla vulgaris	2.7
Lotus corniculatus	2.7
Anthoxanthum odoratum	2.4
Carum carvi	2.3
Dactylis glomerata	2.3
Leontodon hispidus	2.3
Trifolium pratense	2.3
Plantago lanceolata	2.1
Briza media	2.0
Trifolium repens	1.8

7.2 Mountain

Species	**Cov**
Festuca rupicola	15
Bromus erectus	10.3
Briza media	4.4
Koeleria pyramidata	4.4
Thymus serpyllum agg.	3.6
Anthyllis vulneraria	3.4
Lotus corniculatus	3.3
Trifolium pratense	2.8
Achillea millefolium	2.2
Hippocrepis comosa	2.2
Anthoxanthum odoratum	2.1
Genista radiata	2.1
Plantago media	2.1
Acinos alpinus	2
Ranunculus montanus	1.7

Fig. 2.24 Difference in altitude and in forage value between facies (7.1, mesic; 7.2, mountain) and *Mesobromion* type (3).



8. *Seslerio-Caricetum sempervirentis*

Phytosociological nomenclature: *Seslerio-Caricetum sempervirentis* Br.-Bl.

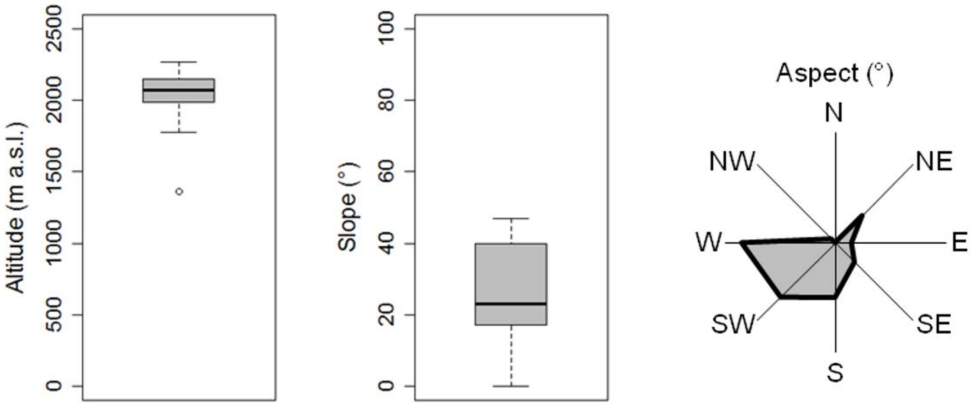
EUNIS classification : E4.43

Corine classification : 36.431-36.432

Topography : Altitude (1950-2150 m a.s.l.); Slope (17-40°); Aspect (SE-W).

Bedrock:

Fig. 2.25 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	**Cov**	**Freq**
Carex sempervirens	14.4	93
Sesleria caerulea	10.7	87
Festuca rubra	4.5	67
Horminum pyrenaicum	4.1	54
Erica carnea	3.6	49
Poa alpina	3.6	57
Anthyllis vulneraria	3.3	75
Thymus serpyllum agg.	3.3	70
Helianthemum grandiflorum	3	50
Lotus alpinus	2.3	62
Ranunculus montanus	1.9	51
Homogyne alpina	1.8	39

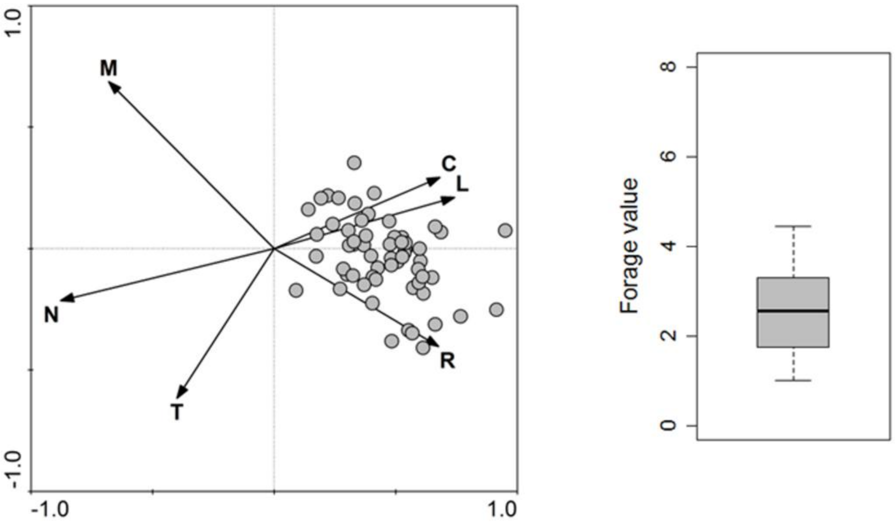
Species	**Cov**	**Freq**
Daphne striata	1.6	39
Trifolium pratense nivale	1.6	36
Oxytropis jacquinii	1.5	26
Anthoxanthum alpinum	1.4	46
Globularia cordifolia	1.4	34
Dryas octopetala	1.2	20
Hieracium pilosella	1.2	38
Onobrychis montana	1.2	11
Alchemilla vulgaris	1.1	30
Leontodon hispidus	1.1	36
Festuca quadriflora	1.0	20
Festuca norica	1.0	23

Characteristic species: *Sesleria caerulea, Carex sempervirens, Horminum pyrenaicum, Erica carnea, Anthyllis vulneraria, Trifolium pratense nivale, Festuca quadriflora, Festuca norica, Oxytropis jacquinii.*

Ecological indicator value: C, continentality (2.9); L, light (3.9); M, moisture (2.2); N, nutrient (2.0); R, reaction (2.9); T, temperature (2.0).

Forage value: 1.7-3.3

Fig. 2.26 PCA ordination of ecological indicator value and boxplot of forage value.

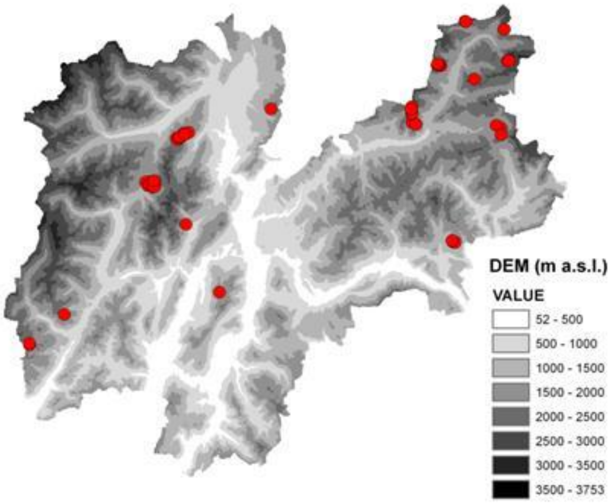


Distribution in the farm: *Seslerio-Caricetum sempervirentis* grasslands are dry community of subalpine and alpine region and located on calcareous bedrock. This community are placed from slope side close to the farm centre to the marginal sites.

Grazing season: from mid-May to mid September.

Average stock rate: 0.4-1.5 LU ha^{-1}.

Fig. 2.27 Location of *Seslerio-Caricetum sempervirentis* grasslands within the Province of Trento.



FACIES

1.9 Acidophillus facies

Characteristic species: *Festuca rubra agg, Nardus stricta, Arnica montana, Geum montanum, Avenella flexuosa, Vaccinium myrtillus.*

1.10 With *Festuca varia*

Characteristic species: *Festuca varia, Juniperus communis alpina, Luzula sieberi, Trifolium alpinum.*

1.11 Shrubbed

Characteristic species: *Pinus mugo, Rhododendron hirsutum.*

8.1 Acidophilus

Species	Cov
Festuca rubra agg.	15.5
Carex sempervirens	12.2
Helianthemum grandiflorum	7.2
Anthoxanthum alpinum	7.0
Anthyllis vulneraria	6.8
Arnica montana	5.6
Vaccinium gaultherioides	4.8
Trifolium pratense nivale	4.4
Nardus stricta	3.6
Sesleria caerulea	2.8
Erica carnea	2.6
Vaccinium myrtillus	2.5
Daphne striata	2.4
Geum montanum	2.2
Avenella flexuosa	1.5

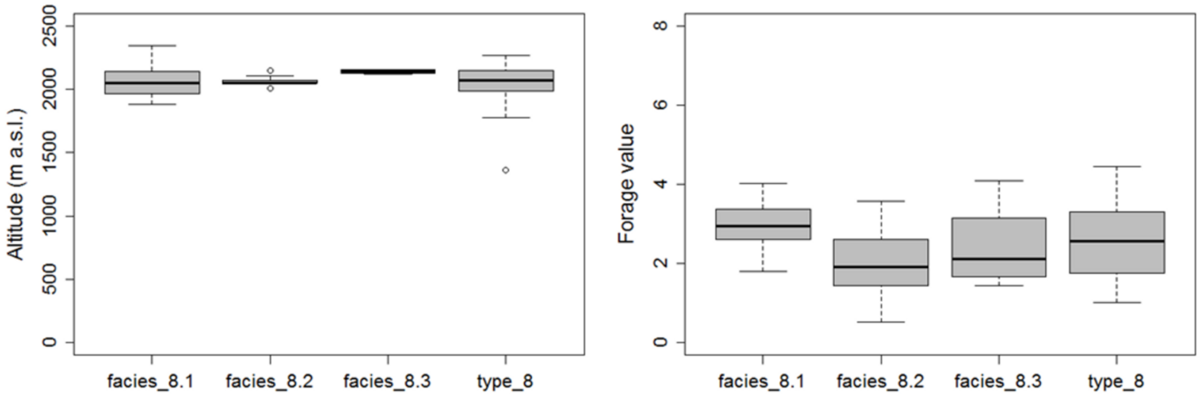
8.2 With *Festuca varia*

Species	Cov
Sesleria caerulea	13.9
Festuca varia	12.1
Juniperus communis alpina	11.2
Pinus cembra	10.6
Carex sempervirens	6.2
Elyna myosuroides	3.3
Vaccinium vitis-idaea	3.3
Erica carnea	3.1
Anthoxanthum alpinum	3.0
Anthyllis vulneraria	1.9
Festuca quadriflora	1.5
Trifolium alpinum	1.5
Luzula sieberi	1.2
Agrostis alpina	1.0
Daphne striata	1.0

8.3 Shrubbed

Species	Cov
Sesleria caerulea	27
Pinus mugo	8.2
Poa alpina	7
Carex sempervirens	6.9
Rhododendron hirsutum	4.3
Elyna myosuroides	3.9
Lotus alpinus	3
Anthyllis vulneraria	2.4
Festuca norica	2.4
Ranunculus montanus	2.1
Erica carnea	2
Antennaria dioica	1.9
Helianthemum grandiflorum	1.9
Hieracium pilosella	1.6
Agrostis alpina	1.1

Fig. 2.28 Difference in altitude and in forage value between facies (8.1, acidophilus; 8.2, with *Festuca varia*; 8.3, shrubbed) and *Seslerio-Caricetum sempervirentis* type (8).



9. *Caricetalia firmae*

Phytosociological nomenclature: *Caricetalia firmae* Gams 1936

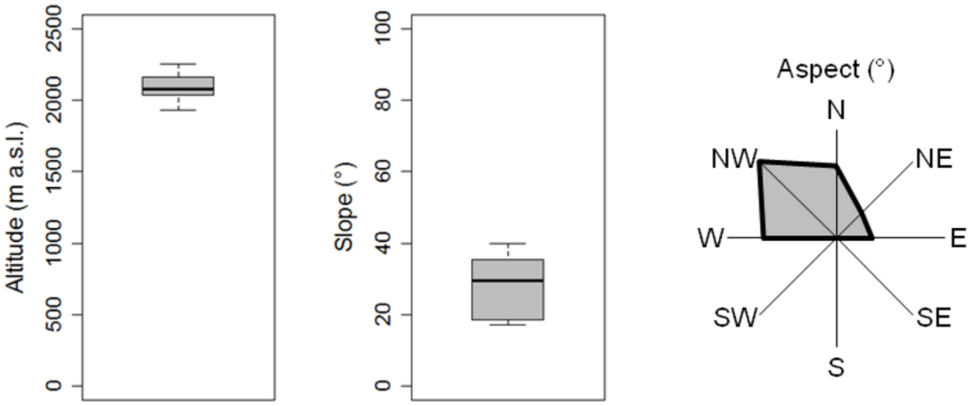
EUNIS classification : E4.43

Corine classification : 36.433

Topography : Altitude (2050-2150 m a.s.l.); Slope (19-35°); Aspect (W-N).

Bedrock:

Fig. 2.29 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	Cov	Freq
Dryas octopetala	13.6	88
Carex firma	10.3	88
Vaccinium gaultherioides	7.5	63
Arctostaphylos alpina	7.4	25
Salix serpillifolia	7.4	25
Sesleria caerulea	4.3	88
Daphne striata	3.9	63
Cetraria islandica	2.6	50
Loiseleuria procumbens	2.6	38
Carex sempervirens	2.5	30
Juniperus communis alpina	2.5	25
Anthyllis vulneraria	1.9	75

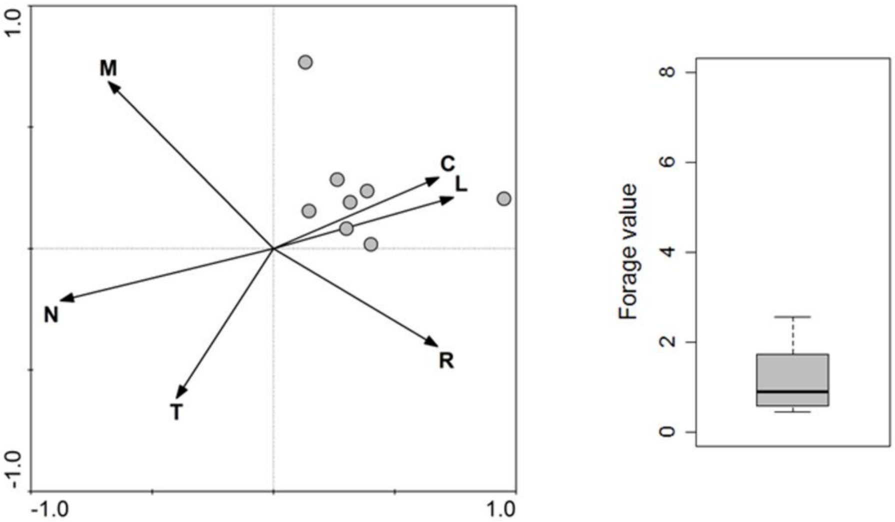
Species	Cov	Freq
Anthoxanthum alpinum	1.5	63
Festuca quadriflora	1.4	38
Homogyne alpina	1.4	38
Antennaria carpatica	1.3	13
Helictotrichon parlatorei	1.3	25
Phyteuma sieberi	1.3	25
Poa alpina	1.3	25
Pulsatilla alpina alpina	1.3	13

Characteristic species: *Carex firma*, *Dryas octopetala*, *Arctostaphylos alpina*, *Sesleria caerulea*, *Daphne striata*, *Phyteuma sieberi*, *Antennaria carpatica*, *Festuca quadriflora*.

Ecological indicator value: C, continentality (2.8); L, light (3.9); M, moisture (2.5); N, nutrient (2.0); R, reaction (2.8); T, temperature (1.9).

Forage value: 0.9-1.9

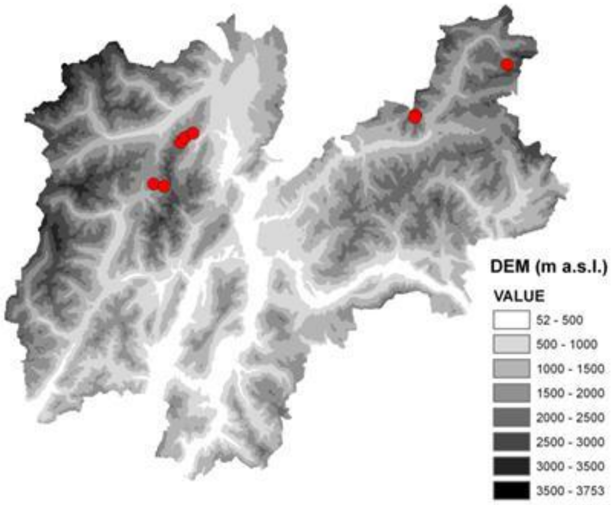
Fig. 2.30 PCA ordination of ecological indicator value and boxplot of forage value.



Distribution in the farm: *Caricion firmae* grasslands are located far from the farm centre, in marginal sites.

Management: This community are not managed or grazed by sheep or goats.

Fig. 2.31 Location of *Caricion firmae* within the Province of Trento.



10. *Homogyno alpinae-Nardetum*

Phytosociological nomenclature: *Homogyno alpinae-Nardetum* Mraz. 1956

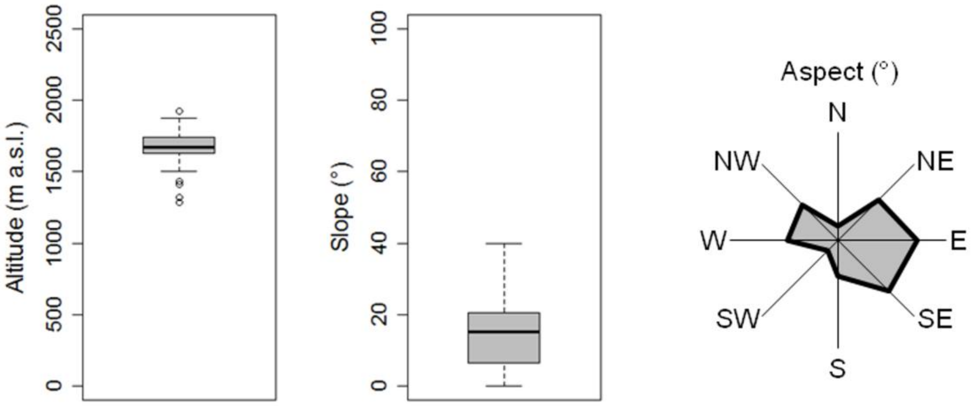
EUNIS classification : E1.71

Corine classification : 35.1

Topography : Altitude (1600-1750 m a.s.l.); Slope (7-20°); Aspect (E-W).

Bedrock:

Fig. 2.32 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	Cov	Freq
Nardus stricta	25.9	100
Festuca rubra agg.	18.2	98
Agrostis capillaris	8.1	90
Potentilla erecta	4.8	92
Vaccinium myrtillus	3.4	68
Calluna vulgaris	3.2	48
Anthoxanthum odoratum	2.8	83
Trifolium repens	2.4	88
Trifolium pratense	2	77
Hieracium lactucella	1.7	77
Hieracium pilosella	1.6	70
Luzula campestris	1.6	73

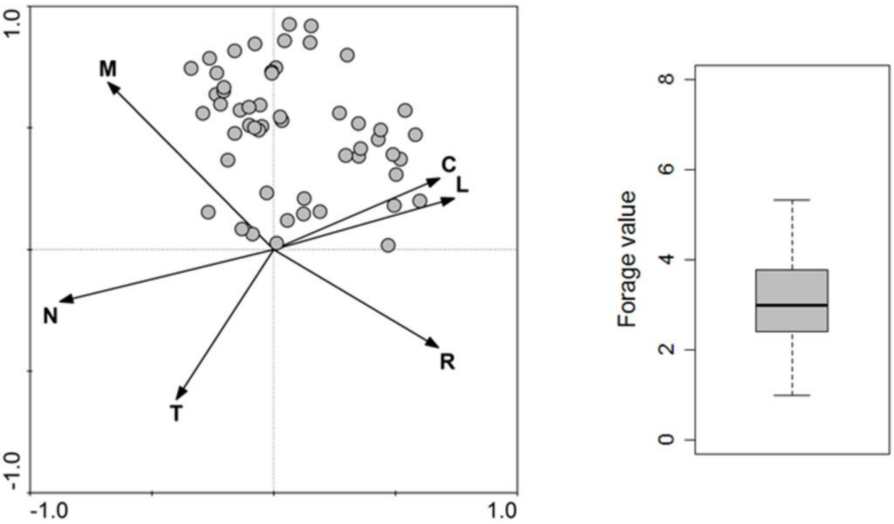
Species	Cov	Freq
Homogyne alpina	1.3	50
Lotus corniculatus	1.2	72
Achillea millefolium millefolium	1.1	70
Carex pallescens	1.1	53
Geum montanum	1.1	50
Potentilla aurea	1.0	33

Characteristic species: *Nardus stricta, Festuca rubra* agg., *Agrostis capillaris, Anthoxanthum odoratum, Hieracium lactucella, Luzula campestris, Homogyne alpina, Carex pallescens.*

Ecological indicator value: C, continentality (2.8); L, light (3.8); M, moisture (2.7); N, nutrient (2.3); R, reaction (2.5); T, temperature (2.1).

Forage value: 2.5-3.8

Fig. 2.33 PCA ordination of ecological indicator value and boxplot of forage value.

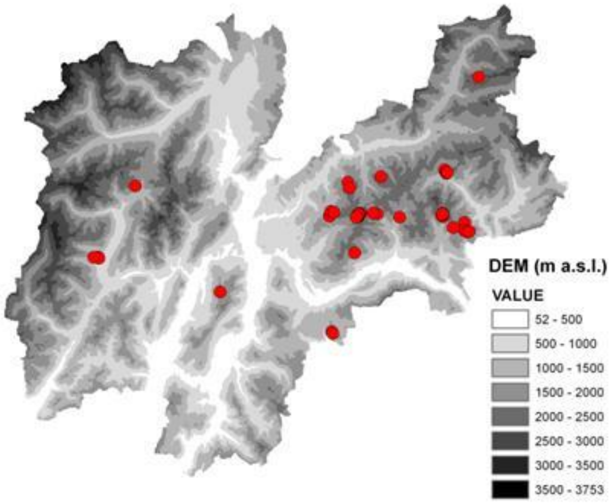


Distribution in the farm: *Homogyno alpinae-Nardetum* grasslands are placed from slope side close to the farm centre to the marginal sites.

Grazing season: from early-mid June to mid September (90-115 days).

Average stock rate: 0.4-1.0 LU ha^{-1}.

Fig. 2.34 Location of *Homogyno alpinae-Nardetum* grasslands within the Province of Trento.



FACIES

1.12 Dry facies

Characteristic species: *Calluna vulgaris, Thymus serpyllum* agg., *Galium anisophyllon, Leucanthemum vulgare, Plantago media, Danthonia decumbens.*

1.13 On calcareous bedrock facies

Characteristic species: *Festuca rupicola, Koeleria pyramidata, Anthyllis vulneraria.*

1.14 Mesic facies

Characteristic species: *Trifolium repens, Trifolium pratense, Phleum rhaeticum, Poa alpina, Leontodon hispidus.*

1.15 Degraded facies

Characteristic species: *Deschampsia cespitosa, Pteridium aquilinum, Cirsium palustre, Cirsium helenioides*

1.16 Shrubbed facies

Characteristic species: *Vaccinium vitis-idaea, Vaccinium myrtillus, Genista tinctoria, Juniperus communis alpina, Picea abies* .

10.1 Dry

Species	Cov
Vaccinium myrtillus	15.8
Vaccinium vitis-idaea	15.8
Nardus stricta	4.3
Calluna vulgaris	3.3
Agrostis capillaris	3.3
Hieracium pilosella	3.0
Lotus corniculatus	3.0
Potentilla erecta	3.0
Prunella vulgaris	3.0
Thymus serpyllum agg.	3.0
Trifolium pratense	3.0
Galium anisophyllon	2.8
Leucanthemum vulgare	2.5
Plantago media	2.4
Danthonia decumbens	2.3

10.2 On calcareous bedrock

Species	Cov
Nardus stricta	14.0
Lotus corniculatus	12.6
Hieracium pilosella	12.0
Centaurea nervosa	9.8
Festuca rupicola	9.8
Festuca rubra agg.	8.7
Trifolium pratense	6.4
Hieracium lactucella	5.9
Anthoxanthum odoratum	4.8
Koeleria pyramidata	4.8
Achillea millefolium	3.9
Leucanthemum vulgare	3.0
Agrostis capillaris	2.5
Briza media	1.3
Anthyllis vulneraria	1.2

10.3 Mesic

Species	Cov
Festuca rubra agg.	14.1
Nardus stricta	11.4
Alchemilla vulgaris	5.5
Trifolium repens	5.5
Agrostis capillaris	4.9
Trifolium pratense	3.9
Phleum rhaeticum	3.7
Deschampsia cespitosa	3.1
Potentilla erecta	3.0
Hieracium lactucella	2.6
Poa alpina	2.5
Anthoxanthum odoratum	2.3
Leontodon hispidus	2.3
Prunella vulgaris	2.2
Hieracium pilosella	2.1

10.4 Degraded

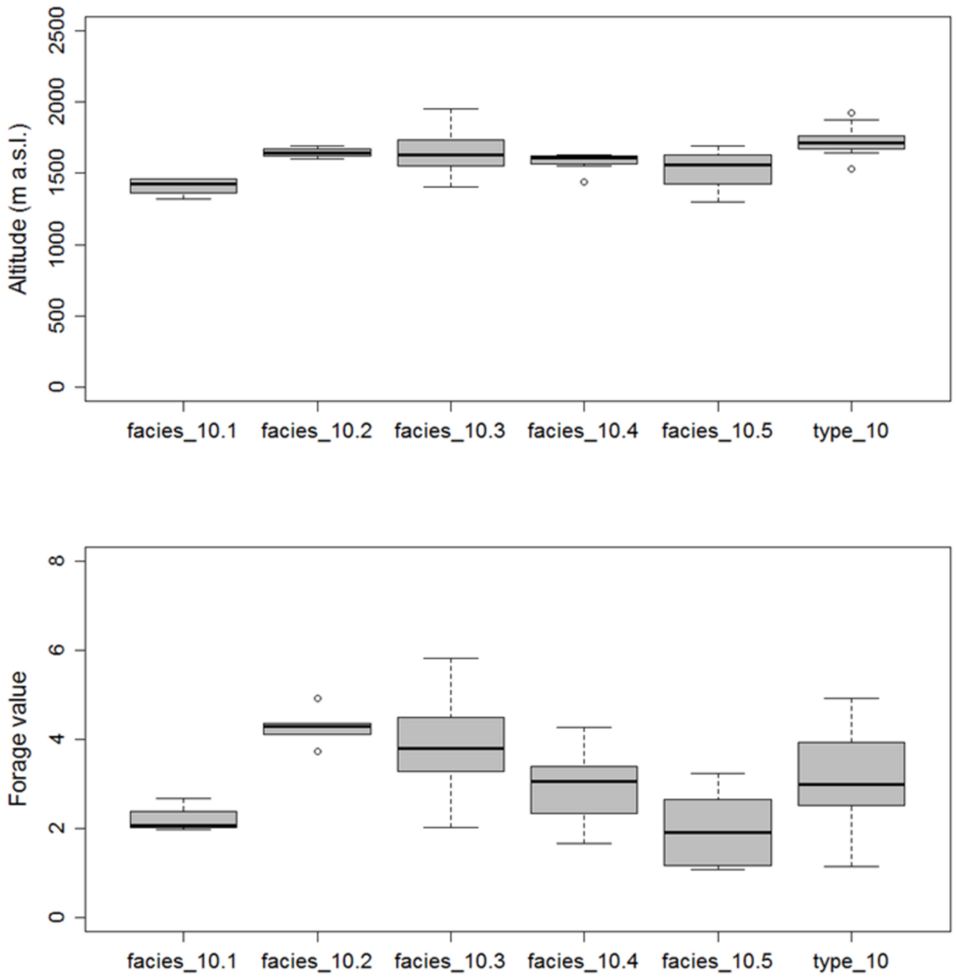
Species	Cov
Deschampsia cespitosa	24.8
Nardus stricta	16.5
Festuca rubra agg.	16.4
Pteridium aquilinum	9.9
Trifolium pratense	3.6
Phleum rhaeticum	2.9

10.5 Shrubbed

Species	Cov
Nardus stricta	15.0
Calluna vulgaris	11.2
Vaccinium vitis-idaea	6.4
Genista tinctoria	6.3
Vaccinium myrtillus	6.2
Festuca rubra agg.	5.9

Agrostis capillaris	2.7	*Potentilla erecta*	5.9
Cirsium palustre	2.5	*Picea abies*	5.6
Trifolium repens	2.5	*Poa alpina*	4.9
Achillea millefolium	2.4	*Agrostis capillaris*	4.5
Vaccinium myrtillus	2.3	*Pteridium aquilinum*	4.1
Ranunculus acris	1.9	*Hieracium pilosella*	4.0
Potentilla erecta	1.7	*Thymus serpyllum* agg.	3.6
Carlina acaulis	1.6	*Juniperus communis alpina*	2.9
Cirsium helenioides	1.6	*Anthoxanthum odoratum*	2.6

Fig. 2.35 Difference in altitude and in forage value between facies (10.1, dry; 10.2, on calcareous bedrock; 10.3, mesic; 10.4, degraded; 10.5, shrubbed) and *Homogyno alpinae-Nardetum* type (10).



11. *Sieversio-Nardetum strictae*

Phytosociological nomenclature: *Sieverso-Nardetum strictae* Lüdi 1948

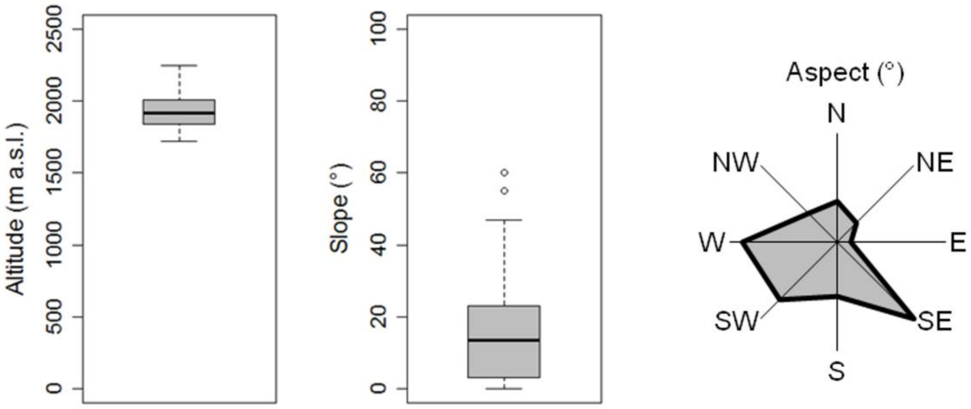
EUNIS classification : E1.71

Corine classification : 35.1

Topography : Altitude (1850-2000 m a.s.l.); Slope (4-23°); Aspect (SE-W).

Bedrock: mainly siliceous bedrock, but also on decalcified substrates.

Fig. 2.36 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	Cov	Freq
Nardus stricta	19.6	89
Festuca gr. rubra	7.3	81
Geum montanum	4.7	93
Arnica montana	4.5	94
Leontodon helveticus	4.0	90
Anthoxanthum alpinum	3.9	83
Vaccinium vitis-idaea	3.3	31
Potentilla aurea	3.2	67
Potentilla erecta	3.0	67
Avenella flexuosa	2.8	67
Poa alpina	2.8	69
Carex sempervirens	2.7	76

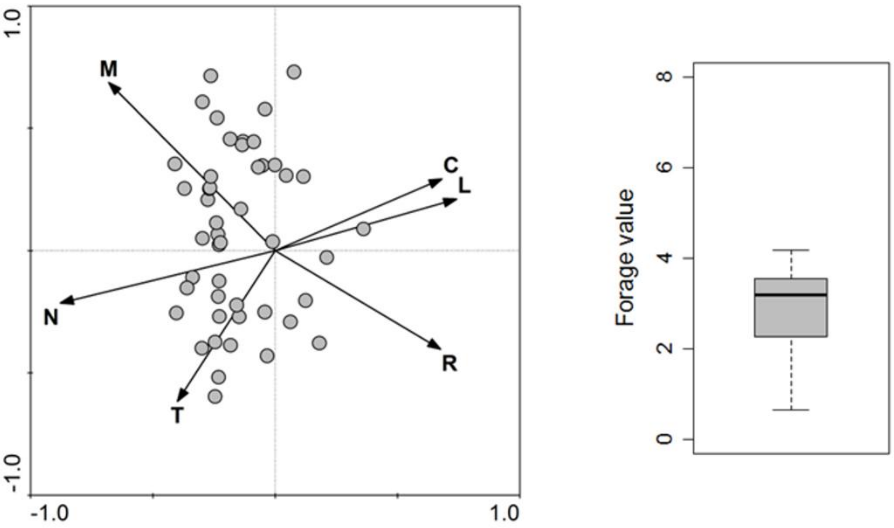
Species	Cov	Freq
Vaccinium myrtillus	2.6	35
Helictotrichon versicolor	2.4	57
Luzula campestris	2.1	70
Juniperus communis alpina	2	20
Calluna vulgaris	1.8	26
Lotus corniculatus	1.6	48
Hieracium lactucella	1.5	48
Phleum rhaeticum	1.5	46
Campanula barbata	1.4	70
Trifolium alpinum	1.4	33
Agrostis capillaris	1.3	44
Phyteuma hemisphaericum	1.2	17

Characteristic species: *Nardus stricta, Festuca rubra* agg., *Agrostis capillaris, Anthoxanthum alpinum, Avenella flexuosa, Carex sempervirens, Helictotrichon versicolor, Geum montanum, Arnica montana Campanula barbata, Trifolium alpinum, Calluna vulgaris.*

Ecological indicator value: C, continentality (2.6); L, light (3.6); M, moisture (2.6); N, nutrient (2.5); R, reaction (2.3); T, temperature (2.4).

Forage value: 2.3-3.5

Fig. 2.37 PCA ordination of ecological indicator value and boxplot of forage value.

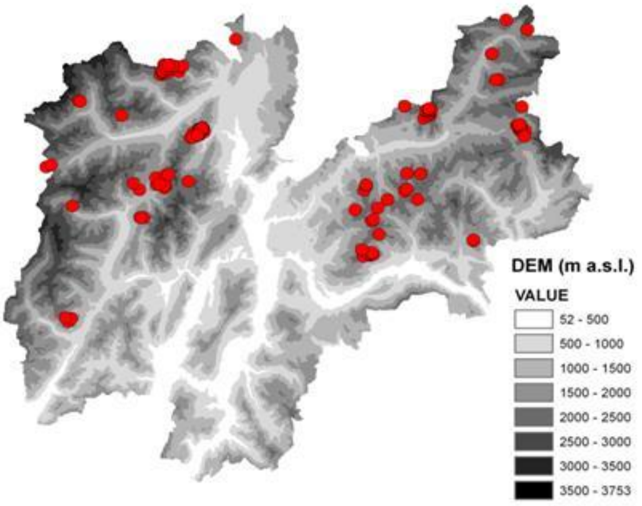


Distribution in the farm: *Sieverso-Nardetum strictae* grasslands are placed from slope side close to the farm centre to the marginal sites.

Grazing season: from late June to early-mid September (60-75 days).

Average stock rate: 0.2-0.9 LU ha^{-1}.

Fig. 2.38 Location of *Sieverso-Nardetum strictae* grasslands within the Province of Trento.



FACIES

1.17 Dry facies

Characteristic species: *Juniperus communis alpina, Calluna vulgaris, Daphne striata.*

1.18 On calcareous bedrock

Characteristic species: *Sesleria caerulea, Anemone baldensis, Horminum pyrenaicum, Anthyllis vulneraria.*

1.19 Mesic facies

Characteristic species: *Poa alpina, Phleum rhaeticum, Trifolium pratense nivale, Trifolium repens, Lotus alpinus, Alchemilla vulgaris.*

1.20 Wet facies

Characteristic species: *Carex nigra, Carex echinata, Carex flava, Deschampsia cespitosa.*

1.21 Degraded facies

Characteristic species: *Deschampsia cespitosa, Chaerophyllum villarsii, Peucedanum ostruthium, Ranunculus acris.*

1.22 Shrubbed facies

Characteristic species: *Rhododendron ferrugineum, Juniperus communis alpina, Vaccinium myrtillus, Vaccinium gaultherioides, Pinus cembra, Larix decidua .*

11.1 Dry

Species	Cov
Juniperus communis alpina	20.0
Nardus stricta	15.0
Calluna vulgaris	9.6
Avenella flexuosa	9.3
Geum montanum	8.2
Arnica montana	5.8
Anthoxanthum alpinum	5.0
Carex sempervirens	4.8
Rhododendron ferrugineum	4.7
Helictotrichon versicolor	4.0
Festuca rubra agg.	3.6
Trifolium alpinum	3.0
Vaccinium gaultherioides	2.2
Juncus trifidus	2.0
Daphne striata	1.4

11.2 On calcareous bedrock

Species	Cov
Nardus stricta	21.1
Festuca rubra agg.	7.8
Carex sempervirens	5.5
Anthoxanthum alpinum	5.3
Geum montanum	4.8
Vaccinium myrtillus	4.8
Vaccinium gaultherioides	4.6
Arnica montana	4.5
Trifolium alpinum	3.7
Anemone baldensis	3.4
Sesleria caerulea	3.0
Leontodon hispidus	2.4
Horminum pyrenaicum	1.1
Anthyllis vulneraria	1.3
Trifolium pratense nivale	1.8

11.3 Mesic

Species	Cov
Festuca rubra agg.	20.3
Nardus stricta	14.5
Deschampsia cespitosa	8.7
Poa alpina	7.2
Alchemilla vulgaris	5.1
Anthoxanthum alpinum	4.4
Phleum rhaeticum	4.3
Trifolium pratense nivale	4.3
Agrostis capillaris	3.9
Trifolium repens	3.5
Leontodon helveticus	3.4
Lotus alpinus	1.0
Potentilla erecta	2.1
Carex sempervirens	1.9
Geum montanum	1.9

11.5 Wet

Species	Cov
Deschampsia cespitosa	17.2
Nardus stricta	11.9
Carex nigra	11.7
Carex echinata	11.1
Festuca rubra agg.	10.8
Anthoxanthum alpinum	4.8
Carex flava	4.8
Potentilla erecta	3.7
Agrostis capillaris	3.2
Phleum rhaeticum	2.9
Carex pallescens	2.8
Luzula campestris	2.6
Poa alpina	1.9
Leontodon helveticus	1.7
Alchemilla vulgaris	1.4

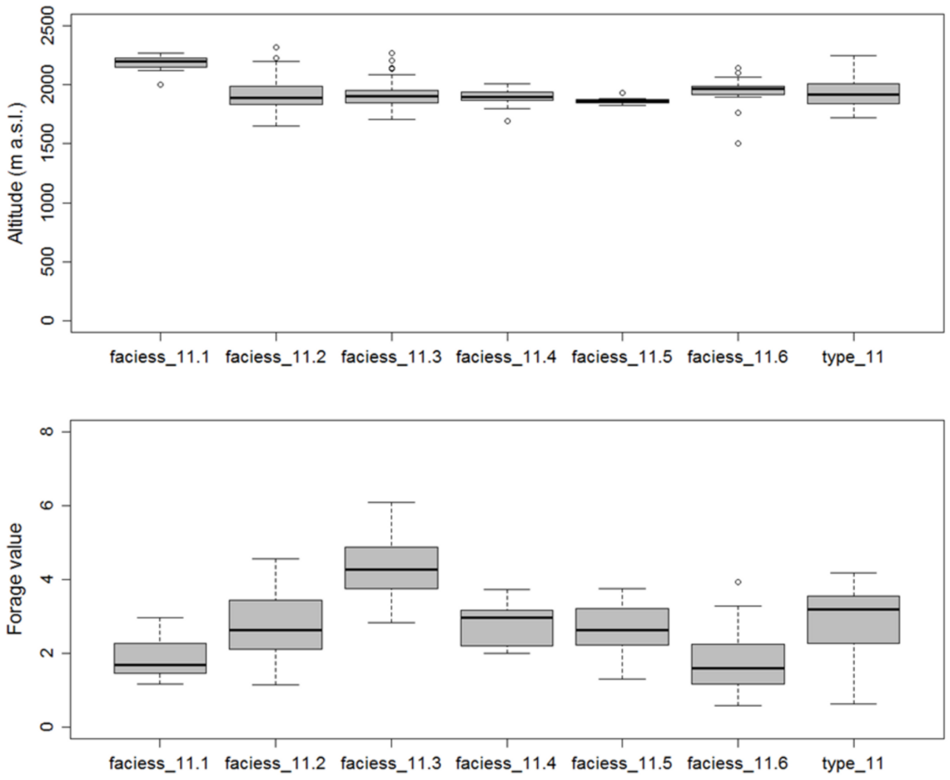
11.6 Degraded

Species	Cov
Deschampsia cespitosa	25.1
Nardus stricta	10.9
Rhododendron ferrugineum	3.8
Trifolium repens	3.8
Festuca rubra agg.	3.7
Alchemilla vulgaris	3.5
Potentilla aurea	3.5
Phleum rhaeticum	3.1
Homogyne alpina	3.0
Hieracium pilosella	2.8
Ranunculus acris	2.8
Poa alpina	2.5
Chaerophyllum villarsii	2.4
Ranunculus montanus	2.2
Peucedanum ostruthium	2.1

11.7 Shrubbed

Species	Cov
Nardus stricta	22.5
Rhododendron ferrugineum	14.3
Juniperus communis alpina	11.3
Festuca rubra agg.	6.5
Vaccinium gaultherioides	4.4
Calluna vulgaris	4.1
Vaccinium myrtillus	3.0
Anthoxanthum alpinum	2.9
Carex pallescens	2.7
Pinus cembra	2.6
Larix decidua	2.5
Potentilla erecta	2.5
Carex sempervirens	2.4
Avenella flexuosa	1.9
Leontodon helveticus	1.8

Fig. 2.39 Difference in altitude and in forage value between facies (11.1, dry; 11.2, on calcareous bedrock; 11.3, mesic; 11.4, wet; 11.5, degraded; 11.6, shrubbed) and *Sieverso-Nardetum strictae* type (11).



12. *Festucetum halleri*

Phytosociological nomenclature: *Festucetum halleri* Br.-Bl. in Br.-Bl. et Jenny 1926

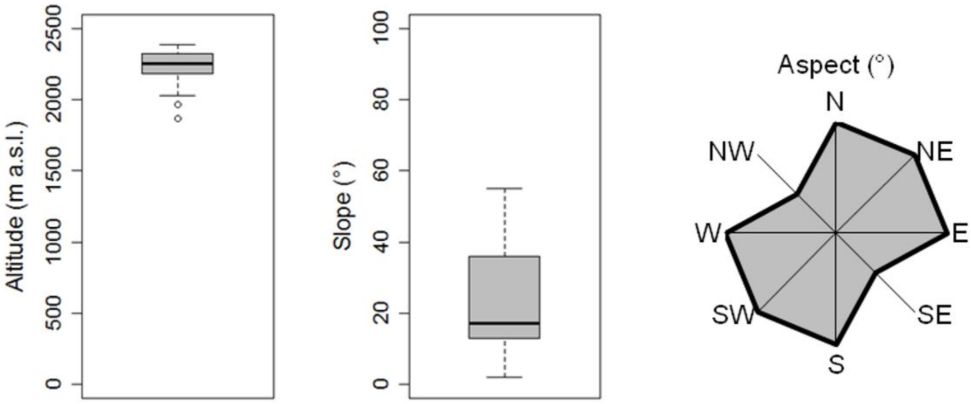
EUNIS classification : E4.34

Corine classification : 36.342

Topography : Altitude (2200-2350 m a.s.l.); Slope (13-30°); Aspect (N-W).

Bedrock: siliceous bedrock

Fig. 2.40 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	Cov	Freq
Festuca halleri	10.7	100
Nardus stricta	7.1	65
Carex sempervirens	6.5	76
Geum montanum	4.6	94
Festuca varia	4.5	35
Poa alpina	4.3	76
Cardamine resedifolia	4.2	47
Helictotrichon versicolor	3.4	80
Anthoxanthum alpinum	3.4	82
Homogyne alpina	3.2	76
Agrostis rupestris	2.8	59
Avenella flexuosa	2.8	53
Arnica montana	2.5	65

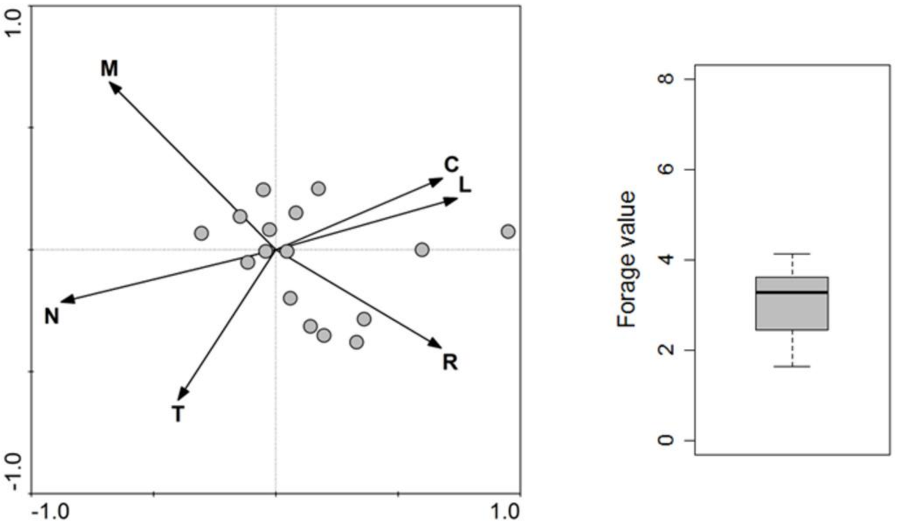
Species	Cov	Freq
Leontodon helveticus	1.9	29
Lotus alpinus	1.7	35
Rhododendron ferrugineum	1.7	24
Pulsatilla alpina apiifolia	1.6	41
Trifolium alpinum	1.6	29
Euphrasia minima	1.5	71
Lotus alpinus	1.5	24
Vaccinium gaultherioides	1.5	24
Ligusticum mutellinoides	1.4	29
Hieracium alpinum	1.3	47
Salix serpillifolia	1.2	6
Alchemilla vulgaris	1.1	29
Cetraria islandica	1	24

Characteristic species: *Festuca halleri, Carex sempervirens, Nardus stricta, Cardamine resedifolia, Helictotrichon versicolor, Anthoxanthum alpinum, Agrostis rupestris, Leontodon helveticus, Pulsatilla alpina apiifolia, Trifolium alpinum, Hieracium alpinum.*

Ecological indicator value: C, continentality (2.7); L, light (3.8); M, moisture (2.3); N, nutrient (2.3); R, reaction (2.5); T, temperature (2.3).

Forage value: 2.4-3.7

Fig. 2.41 PCA ordination of ecological indicator value and boxplot of forage value.

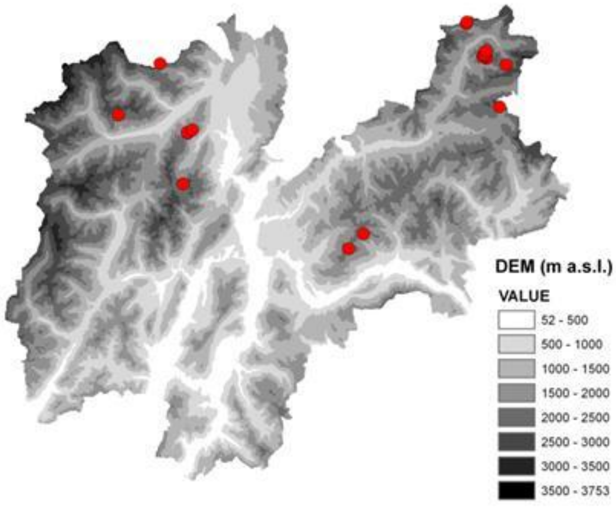


Distribution in the farm: *Festucetum halleri* grasslands are located far from the farm centre, in marginal sites.

Grazing season: from early July to early September (60 days).

Average stock rate: 0.1-0.6 LU ha^{-1}.

Fig.2.42 Location of *Festucetum halleri* within the Province of Trento.



13. *Festucion varie*

Phytosociological nomenclature: *Festucion varie* Guinochet 1938

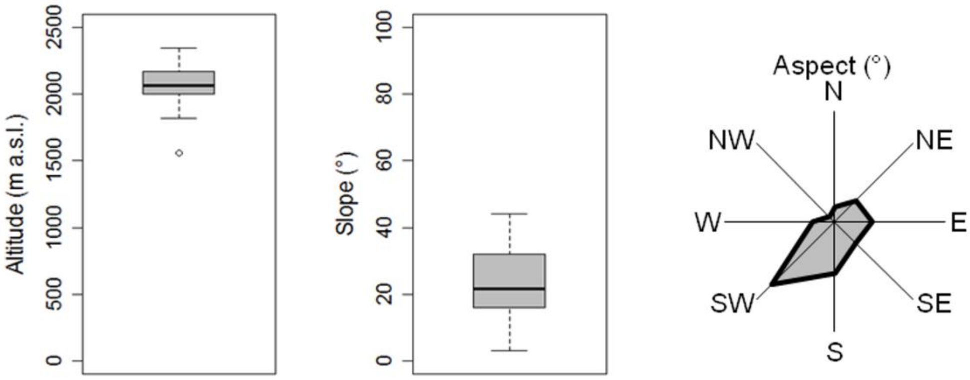
EUNIS classification : E4.333

Corine classification : 36.333

Topography : Altitude (2000-2200 m a.s.l.); Slope (16-31°); Aspect (SE-SW).

Bedrock: mainly siliceous bedrock, but also on decalcified substrates.

Fig. .2.43 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	Cov	Freq
Festuca varia	32.3	100
Nardus stricta	8.7	67
Carex sempervirens	7.7	92
Avenella flexuosa	2.7	62
Festuca rubra agg.	2.6	44
Anthoxanthum alpinum	2.3	67
Juncus trifidus	1.9	49
Arnica montana	1.8	67
Calluna vulgaris	1.7	49
Geum montanum	1.6	56
Leontodon helveticus	2	45
Poa alpina	1.2	33
Potentilla aurea	1.2	41

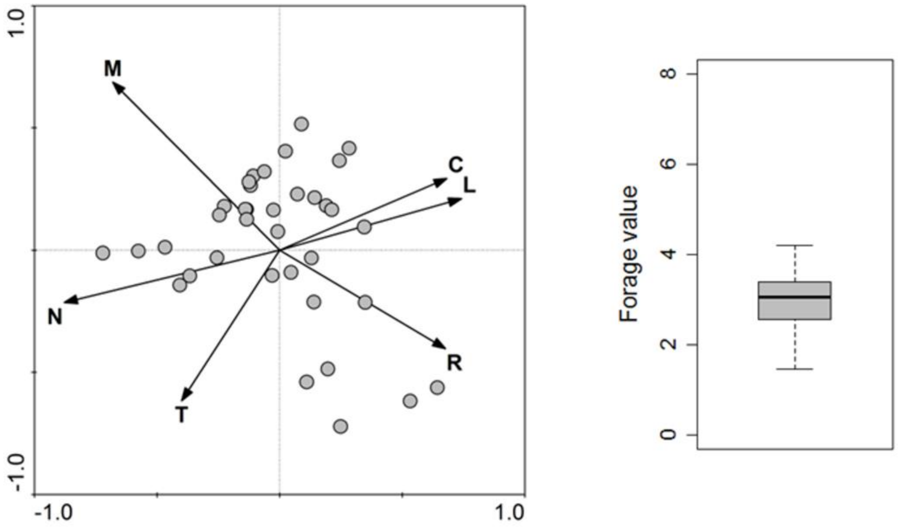
Species	Cov	Freq
Arctostaphylos uva-ursi	1.1	10
Loiseleuria procumbens	1.1	18
Potentilla erecta	1.1	44

Characteristic species: *Festuca varia, Carex sempervirens, Avenella flexuosa, Anthoxanthum alpinum, Juncus trifidus***,** *Calluna vulgaris, Geum montanum, Leontodon helveticus, Potentilla aurea.*

Ecological indicator value: C, continentality (2.6); L, light (3.6); M, moisture (2.4); N, nutrient (2.4); R, reaction (2.3); T, temperature (2.2).

Forage value: 2.6-3.4

Fig. 2.44 PCA ordination of ecological indicator value and boxplot of forage value.

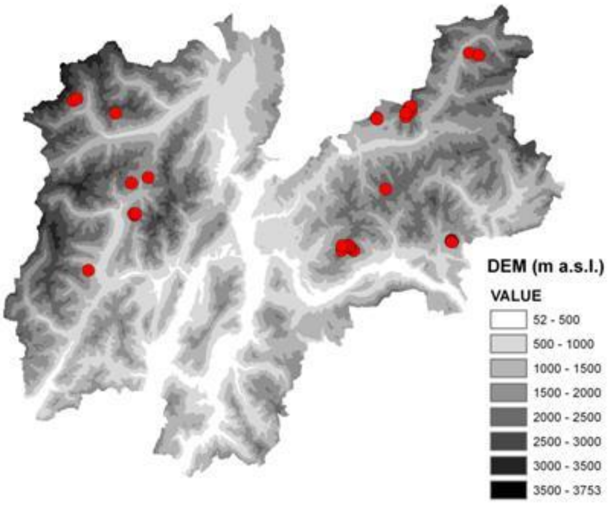


Distribution in the farm: *Festucion varie* grasslands grasslands are located far from the farm centre, in marginal sites.

Grazing season: from mid June to mid September (90 days).

Average stock rate: 0.1-0.6 LU ha^{-1}.

Fig. 2.45 Location of *Festucion varie* grasslands within the Province of Trento.



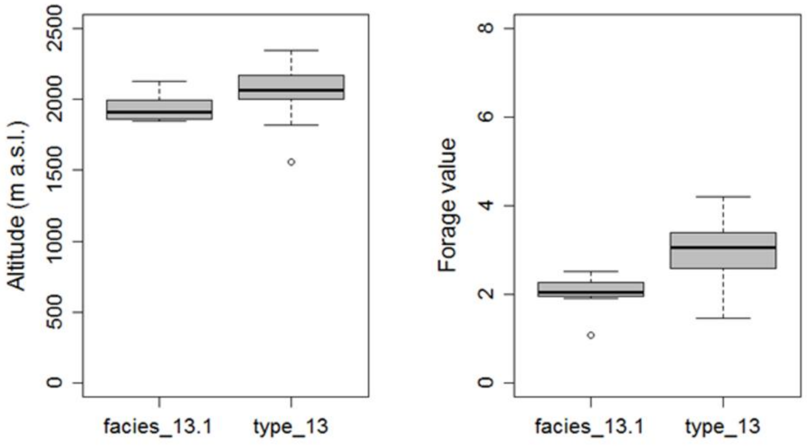
FACIES

1.23 Shrubbed

Characteristic species: *Juniperus communis alpina*, *Rhododendron ferrugineum*, *Vaccinium myrtillus*, *Calluna vulgaris*, *Vaccinium gaultherioides*.

13.1 Shrubbed	
Species	**Cov**
Festuca varia	25.5
Juniperus communis alpina	11.8
Rhododendron ferrugineum	10.4
Vaccinium myrtillus	6.1
Carex sempervirens	4.6
Anthoxanthum alpinum	4.4
Calluna vulgaris	3.4
Vaccinium gaultherioides	3.3
Avenella flexuosa	2.6
Arnica montana	2.4
Nardus stricta	2.4
Thymus serpyllum agg.	1.5
Agrostis rupestris	1.3
Festuca halleri	1.3
Helictotrichon versicolor	1.3

Fig. 2.46 Difference in altitude and in forage value between facies (13.1, shrubbed) and *Festucion varie* type (13).



14. *Loiseleurio-Vaccinion*

Phytosociological nomenclature: *Loiseleurio-Vaccinion* Br.-Bl. in Br.-Bl. et Jenny 1926

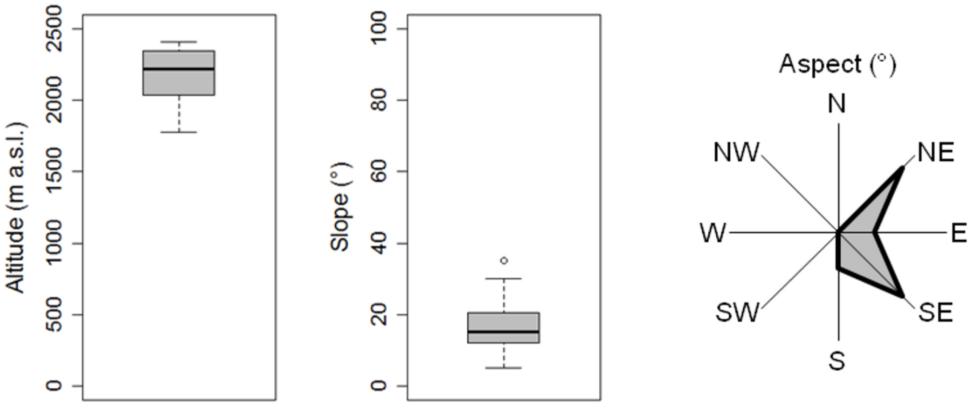
EUNIS classification : F2.21

Corine classification : 31.41

Topography : Altitude (2050-2350 m a.s.l.); Slope (13-30°); Aspect (NE-SE).

Bedrock: mainly siliceous bedrock, but also on decalcified substrates.

Fig. 2.47 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	Cov	Freq
Loiseleuria procumbens	25.1	87
Vaccinium myrtillus	10	80
Cetraria islandica	9.1	87
Agrostis rupestris	5.3	40
Helictotrichon versicolor	5.1	60
Carex sempervirens	5.0	87
Pleurozium schreberi	4.5	47
Juncus trifidus	4.0	53
Carex curvula	3.6	47
Geum montanum	2.6	60
Avenella flexuosa	2.1	53
Nardus stricta	1.9	33
Primula minima	1.7	40

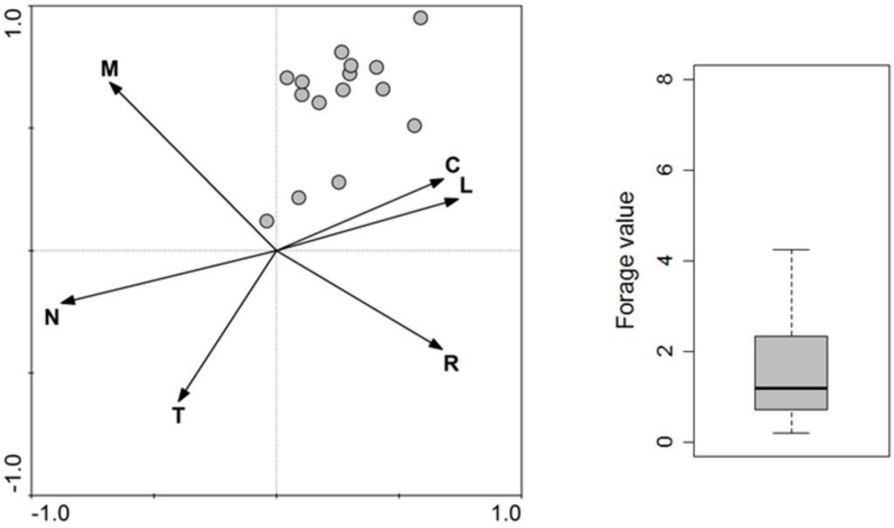
Species	Cov	Freq
Saponaria pumila	1.7	40
Thesium alpinum	1.4	27
Salix retusa	1.3	7
Homogyne alpina	1.0	47
Euphrasia minima	1.0	40
Festuca halleri	1.0	40

Characteristic species: *Loiseleuria procumbens, Cetraria islandica, Vaccinium gaultherioides, Agrostis rupestris, Helictotrichon versicolor, Juncus trifidus, Carex curvula, Primula minima, Salix retusa, Trifolium alpinum, Pleurozium schreberi, Saponaria pumila.*

Ecological indicator value: C, continentality (3.0); L, light (4.0); M, moisture (2.6); N, nutrient (2.0); R, reaction (2.2); T, temperature (1.8).

Forage value: 0.7-2.3

Fig. 2.48 PCA ordination of ecological indicator value and boxplot of forage value.

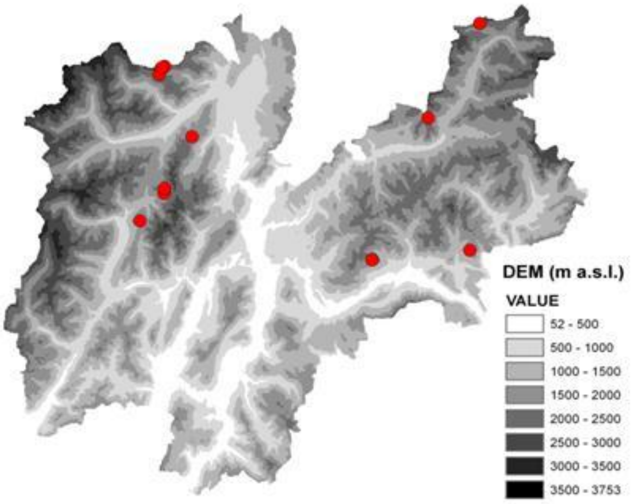


Distribution in the farm: *Loiseleurio-Vaccinion* grasslands are located far from the farm centre, in marginal sites.

Grazing season: from July to August (60 days).

Average stock rate: 0-0.2 LU ha^{-1}.

Fig. 2.49 Location of *Loiseleurio-Vaccinion* within the Province of Trento.



15. Fens

Phytosociological nomenclature: *Drepanoclado revolventis-Trichophoretum caespitosi* Gerdol & Tomaselli 1997

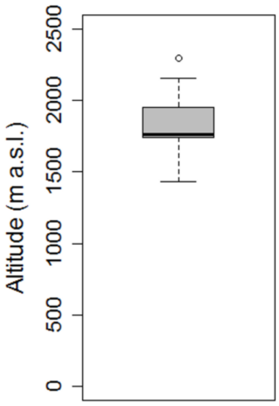
EUNIS classification : D2.25

Corine classification : 54.45

Topography : Altitude (1750-1950 m a.s.l.); Slope (0°); Aspect (-).

Bedrock: indifferent to the type of substrate

Fig. 2.50 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	Cov	Freq
Trichophorum cespitosum	14.1	53
Molinia caerulea	5.4	73
Trichophorum alpinum	5.2	27
Potentilla erecta	4.8	93
Eriophorum scheuchzeri	4.7	47
Nardus stricta	3.7	53
Carex flava	3.4	33
Carex echinata	2.9	87
Carex rostrata	2.9	40
Carex nigra	2.7	33
Calluna vulgaris	2.2	60
Vaccinium uliginosum	2.2	60
Vaccinium vitis-idaea	2.1	33

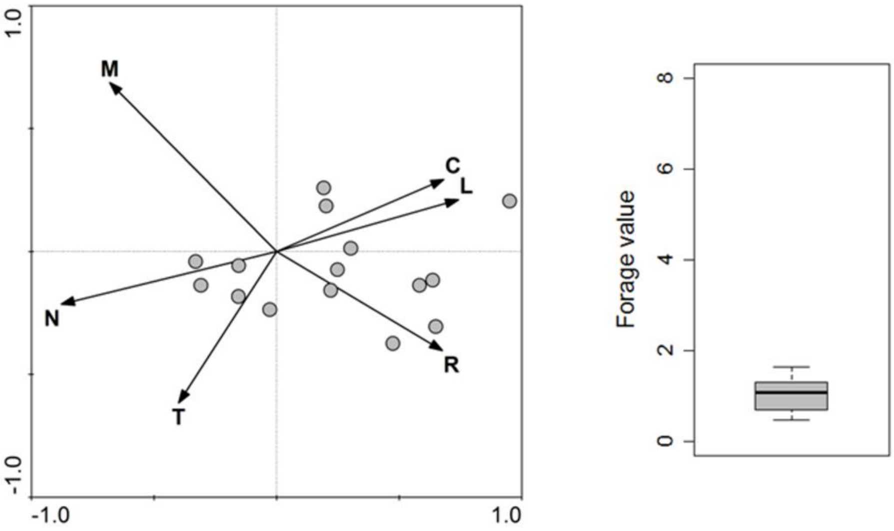
Species	Cov	Freq
Carex frigida	2.0	20
Eriophorum angustifolium	2.0	27
Deschampsia cespitosa	1.9	40
Festuca rubra agg.	1.8	33
Anthoxanthum odoratum	1.7	33
Parnassia palustris	1.7	47
Homogyne alpina	1.0	33

Characteristic species: *Trichophorum cespitosum, Trichophorum alpinum, Molinia caerulea, Eriophorum scheuchzeri, Carex flava, Carex echinata, Carex rostrata, Carex nigra, Carex frigida, Eriophorum angustifolium, Parnassia palustris.*

Ecological indicator value: C, continentality (2.8); L, light (3.9); M, moisture (2.3); N, nutrient (2.4); R, reaction (2.8); T, temperature (2.0).

Forage value: 0.7-1.3

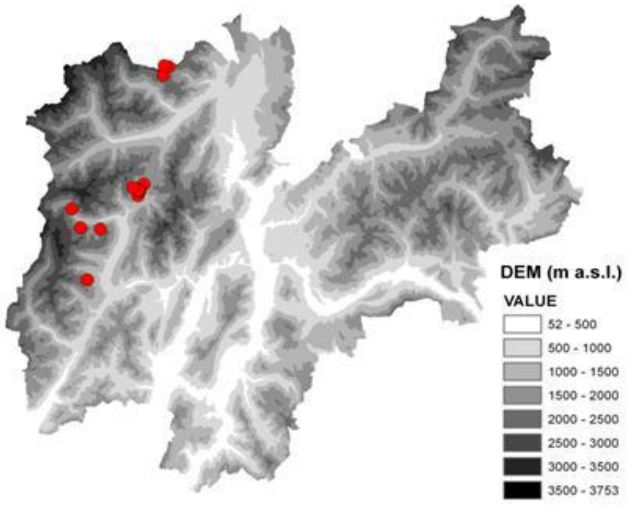
Fig. 2.51 PCA ordination of ecological indicator value and boxplot of forage value.



Distribution in the farm: wet communities on dip sites.

Management: sites subject to occasional grazing.

Fig. 2.52 Location of bog within the Province of Trento.



A. Shrubbed pastures

A1. *Rhododendretum ferruginei*

Phytosociological nomenclature: *Rhododendretum ferruginei* Rübel 1911

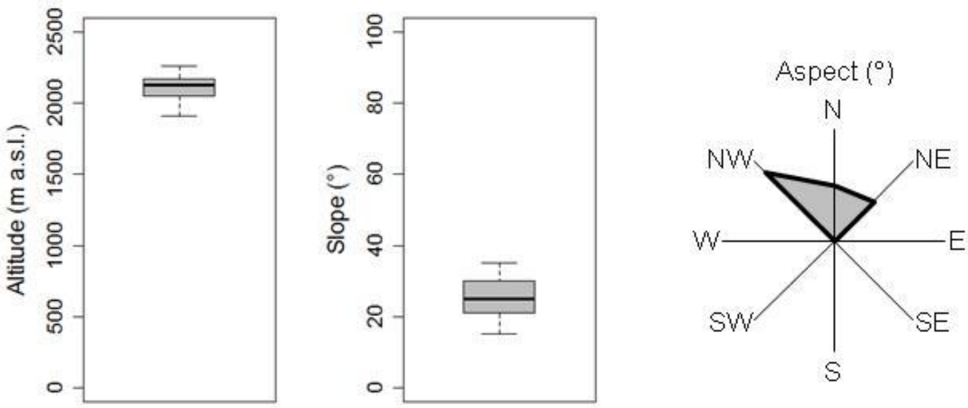
EUNIS classification : F2.222

Corine classification : 31.42

Topography : Altitude (2050-2200 m a.s.l.); Slope (21°-30°); Aspect (NW-NE).

Bedrock: mainly siliceous bedrock, but also on decalcified substrates.

Fig. 2.53 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

Species	Cov	Freq
Rhododendron ferrugineum	34.3	91
Vaccinium gaultherioides	26.2	100
Vaccinium myrtillus	7.2	73
Juniperus communis alpina	5.5	73
Juncus trifidus	4.5	45
Avenella flexuosa	3.9	91
Helictotrichon versicolor	3.9	82
Homogyne alpina	3.9	91
Nardus stricta	2.9	55
Gentiana punctata	2.1	73
Anthoxanthum alpinum	1.2	73

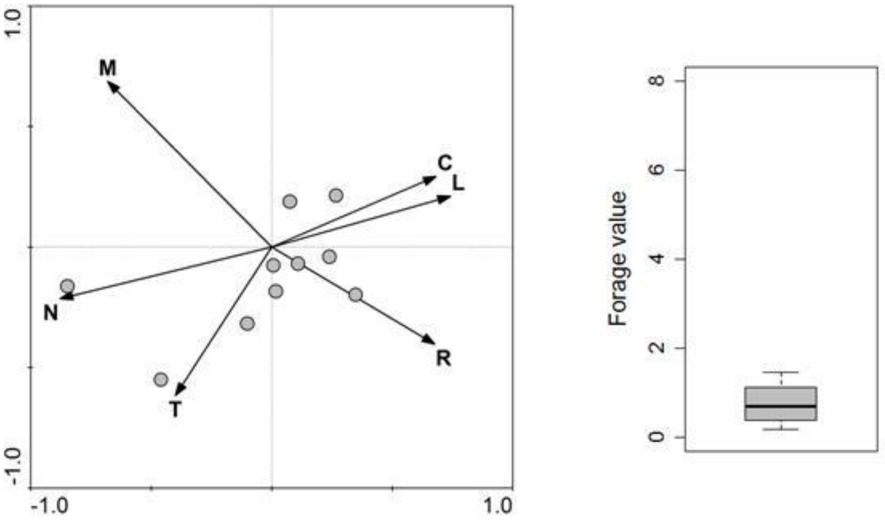
Species	Cov	Freq
Festuca varia	1.1	45
Geum montanum	1.1	45
Cetraria islandica	1.1	55
Leontodon helveticus	1.1	55
Luzula alpinopilosa	1.1	45
Agrostis rupestris	1.0	18
Arnica montana	1.0	27
Deschampsia cespitosa	1.0	18

Characteristic species: *Rhododendron ferrugineum, Vaccinium gaultherioides, Vaccinium myrtillus, Juniperus communis alpina, Avenella flexuosa.*

Ecological indicator value: C, continentality (2.5); L, light (3.7); M, moisture (2.3); N, nutrient (2.4); R, reaction (2.3); T, temperature (2.3).

Forage value: 0.4-1.1

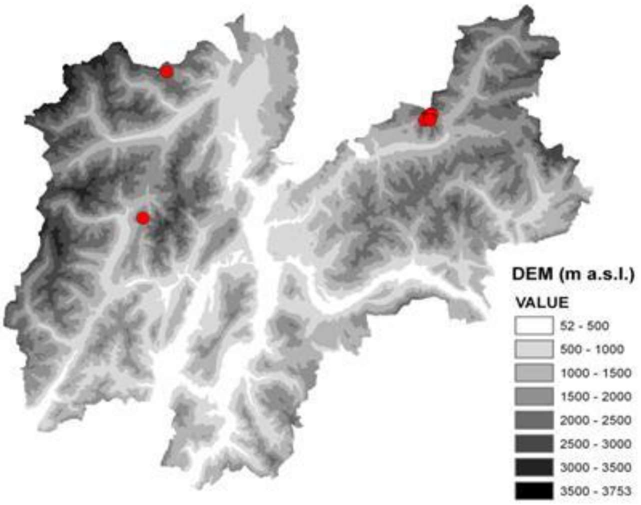
Fig. 2.54 PCA ordination of ecological indicator value and boxplot of forage value.



Distribution in the farm: *Rhododendretum ferruginei* grasslands are located far from the farm centre, in marginal sites.

Management: sites subject to occasional grazing or abandoment.

Fig. 2.55 Location of *Rhododendretum ferruginei* within the Province of Trento.



A2. *Alnetum viridis*

Phytosociological nomenclature: *Alnetum viridis* Br.-Bl. 1918

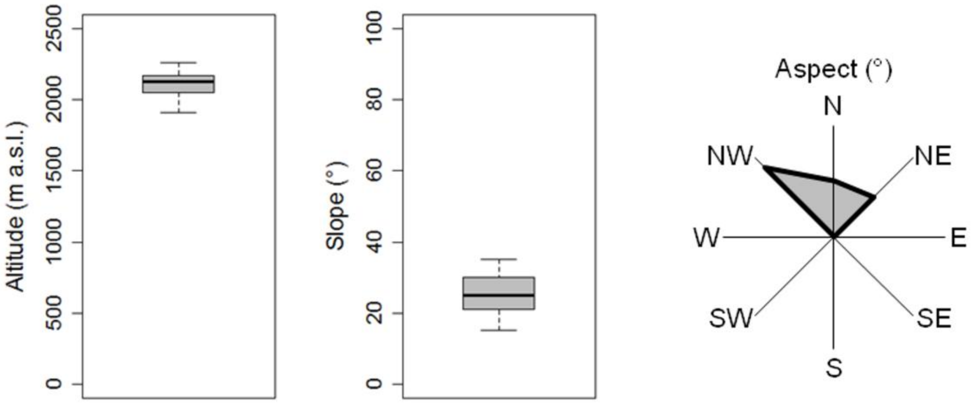
EUNIS classification : F2.31

Corine classification : 31.61

Topography : Altitude (1800-1950 m a.s.l.); Slope (21°-30°); Aspect (N-E).

Bedrock: mainly siliceous bedrock, but also on decalcified substrates.

Fig. 2.56 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

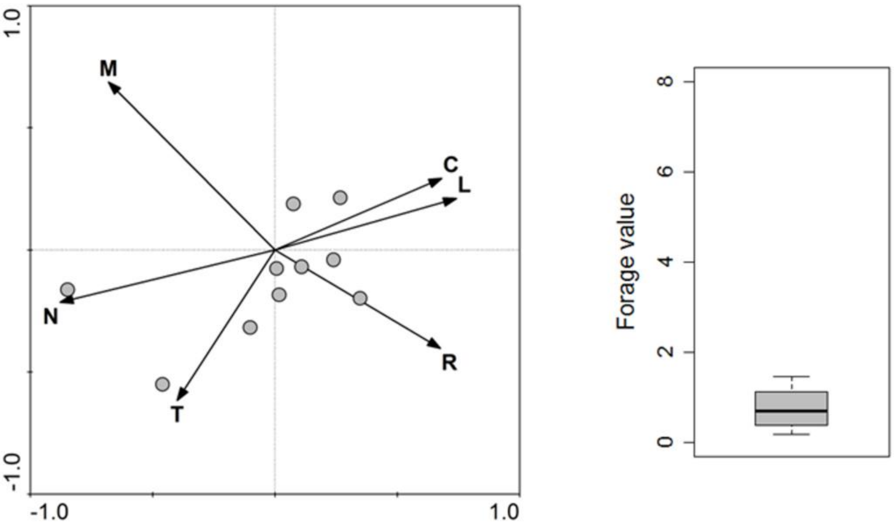
Species	Cov	Freq
Alnus viridis	49.4	100
Rhododendron ferrugineum	13.8	92
Adenostyles alliariae	11.4	58
Cicerbita alpina	10.1	100
Vaccinium myrtillus	7.1	83
Calamagrostis villosa	7.0	58
Aconitum napellus tauricum	6.3	100
Larix decidua	5.6	50
Festuca gr.rubra	5.3	67
Picea abies	4.0	40
Senecio germanicus glabratus	4.0	40
Pinus cembra	3.5	33
Agrostis capillaris	2.2	60
Anthoxanthum odoratum	2.2	60
Agrostis schraderiana	2.2	60
Trifolium pratense pratense	2.2	60
Peucedanum ostruthium	2.0	20
Trollius europaeus	2.0	20
Avenella flexuosa	1.0	75

Characteristic species: *Alnus viridis, Rhododendron ferrugineum, Adenostyles alliariae, Cicerbita alpina, Agrostis schraderiana, Peucedanum ostruthium, Trollius europaeus.*

Ecological indicator value: C, continentality (2.4); L, light (3.5); M, moisture (2.7); N, nutrient (2.6); R, reaction (2.3); T, temperature (2.2).

Forage value: 0.2-1.3

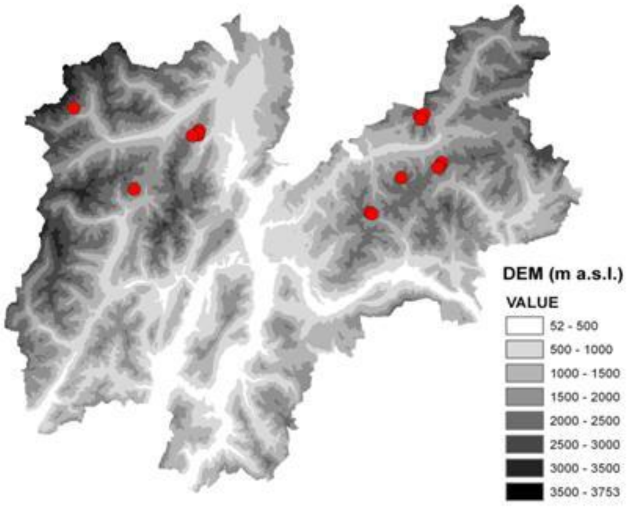
Fig. 2.57 PCA ordination of ecological indicator value and boxplot of forage value.



Distribution in the farm: *Alnetum viridis* grasslands are located far from the farm centre, in marginal sites.

Management: sites subject to abandoment.

Fig. 2.58 Location of *Alnetum viridis* within the Province of Trento.



A3. *Erico-Pinion mugo*

Phytosociological nomenclature: *Erico-Pinion mugo* Leibundgut 1948

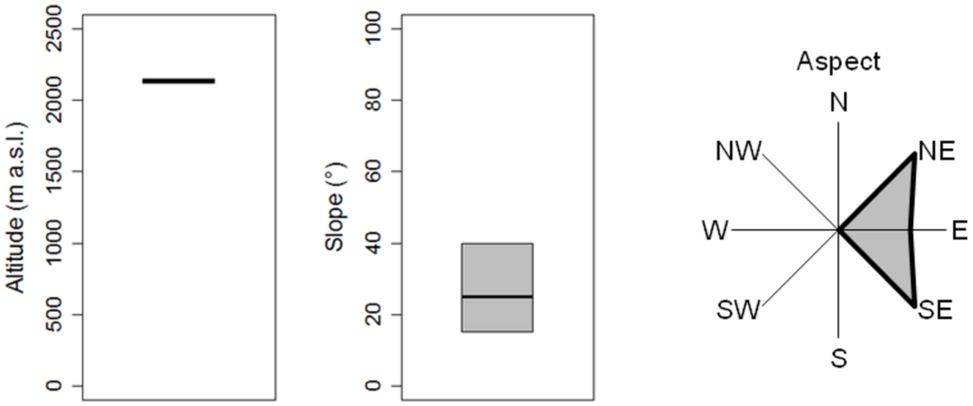
EUNIS classification : F2.42

Corine classification : 31.5

Topography : Altitude (2100-2150 m a.s.l.); Slope (15°-40°); Aspect (NE-SE).

Bedrock: calcareous bedrock.

Fig. 2.59 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

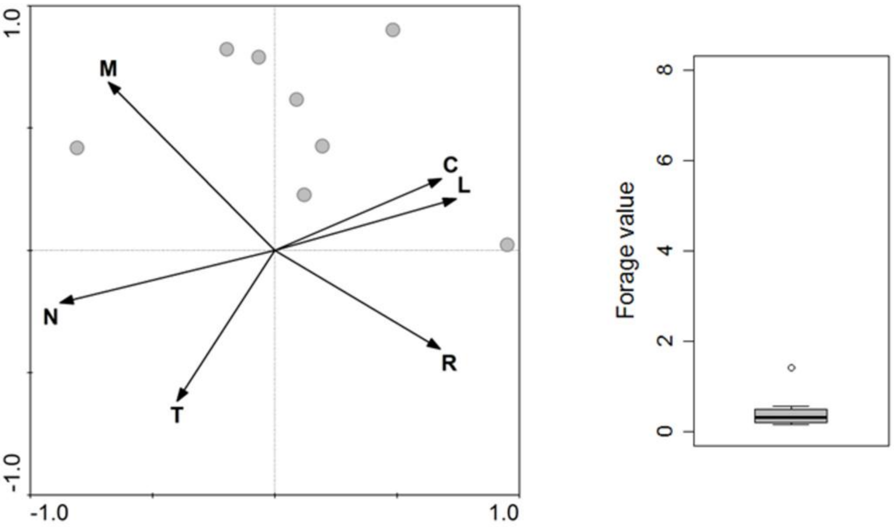
Species	Cov	Freq
Pinus mugo	44	100
Pinus cembra	30.6	100
Rhododendron hirsutum	22.3	63
Juniperus communis alpina	7.7	88
Erica carnea	3.3	38
Avenella flexuosa	2.7	100
Vaccinium myrtillus	2.6	88
Calamagrostis varia	2.5	50
Homogyne alpina	2.1	100
Sesleria caerulea	1.7	88
Poa alpina	1.6	63
Larix decidua	1.3	75
Luzula sieberi	1.3	63
Vaccinium gaultherioides	1.1	38

Characteristic species: *Pinus mugo, Rhododendron hirsutum, Pinus cembra, Larix decidua, Juniperus communis alpina, Erica carnea, Calamagrostis varia.*

Ecological indicator value: C, continentality (2.9); L, light (3.3); M, moisture (2.5); N, nutrient (2.2); R, reaction (2.3); T, temperature (2.1).

Forage value: 0.2-0.5

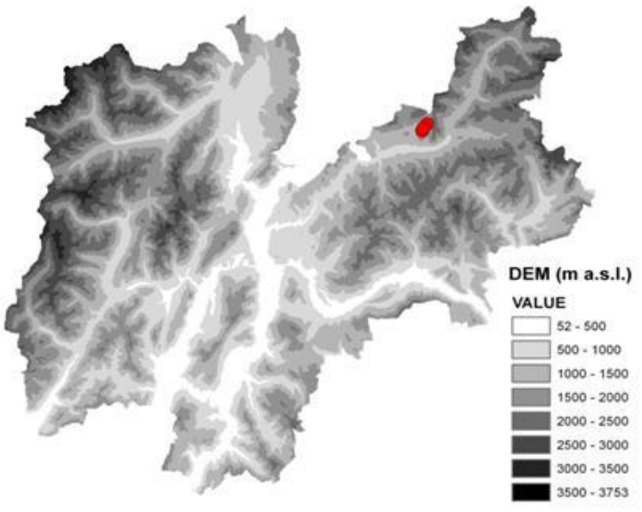
Fig. 2.60 PCA ordination of ecological indicator value and boxplot of forage value.



Distribution in the farm: *Erico-Pinion mugo* grasslands are located far from the farm centre, in marginal sites.

Management: sites subject to abandoment.

Fig. 2.61 Location of *Erico-Pinion mugo* within the Province of Trento.



B.Refforested pastures

B1. *Larici-Pinetum cembrae*

Phytosociological nomenclature: *Larici-Pinetum cembrae* Ellenberg 1963

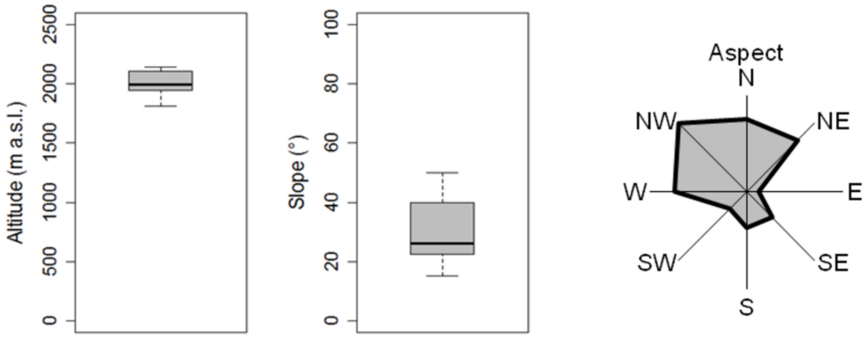
EUNIS classification : G3.2

Corine classification : 42.3

Topography : Altitude (1950-2100 m a.s.l.); Slope (23°-40°); Aspect (W-NE).

Bedrock: mainly siliceous bedrock, but also on decalcified substrates.

Fig. 2.62 Boxplot of altitude, slope, and polar coordinate plot of aspect.



Species composition:

On calcareous bedrock	
Species	**Cov**
Rhododendron hirsutum	33.9
Pinus cembra	20.6
Vaccinium myrtillus	10.7
Larix decidua	10
Juniperus communis alpina	10
Vaccinium vitis-idaea	7.5
Sesleria caerulea	6
Vaccinium gaultherioides	4.1
Agrostis schraderiana	2.6
Avenella flexuosa	2.5
Homogyne alpina	1.9
Calamagrostis villosa	1.8
Erica carnea	1.5

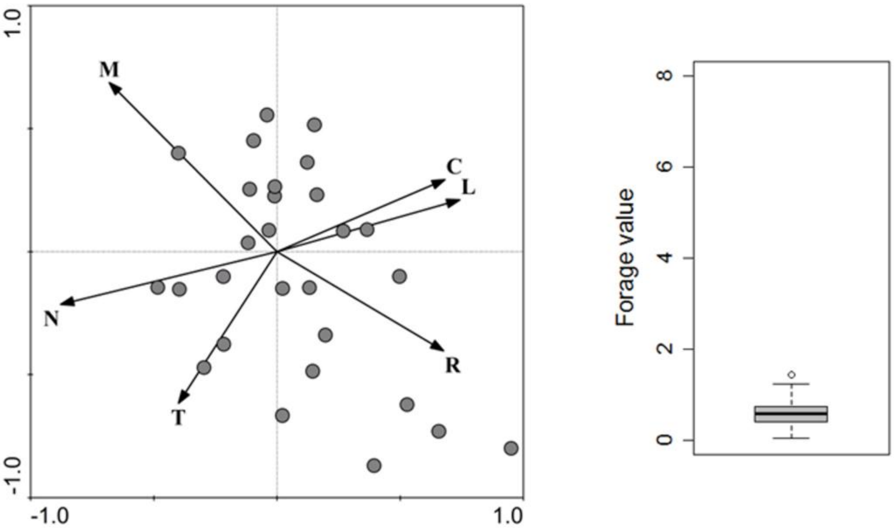
On acid bedrock	
Species	**Cov**
Calamagrostis villosa	36.5
Pinus cembra	21.5
Picea abies	18.9
Vaccinium myrtillus	15.8
Rhododendron ferrugineum	9.6
Larix decidua	6.8
Juniperus communis alpina	5.8
Avenella flexuosa	5.7
Nardus stricta	3.2
Calluna vulgaris	2.6
Adenostyles alliariae	2
Luzula sieberi	2
Anthoxanthum odoratum	1.9

Characteristic species: *Pinus cembra, Larix decidua, Picea abies, Rhododendron hirsutum, Rhododendron ferrugineum, Vaccinium myrtillus, Calamagrostis villosa, Avenella flexuosa.*

Ecological indicator value: C, continentality (2.7); L, light (3.6); M, moisture (2.4); N, nutrient (2.3); R, reaction (2.5); T, temperature (2.3).

Forage value: 0.4-1.1

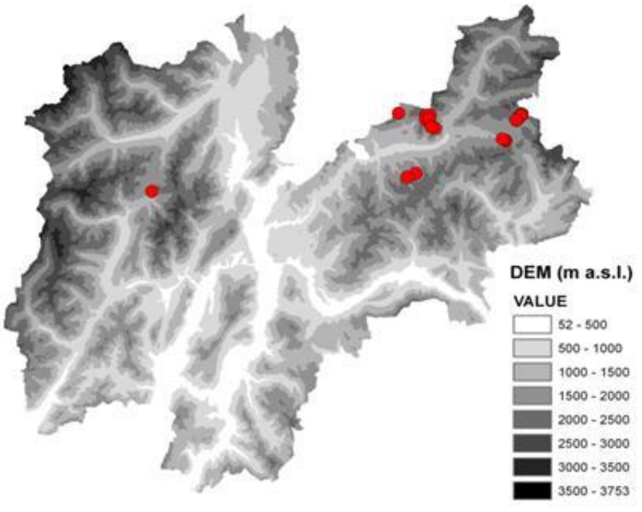
Fig. 2.63 PCA ordination of ecological indicator value and boxplot of forage value.



Distribution in the farm: *Larici-Pinetum cembrae* grasslands are located far from the farm centre, in marginal sites.

Management: sites subject to occasional grazing or abandoment.

Fig. 2.64 Location of *Larici-Pinetum cembrae* within the Province of Trento.



DISCUSSION

The elaboration of more than 1500 vegetation relevees, analyzed by cluster analysis, made it possible to classify the most common types of pasture in the Province of Trento. It has allowed to identify four main groups of pastures (a, mesic and degraded pastures; b, pastures on calcareous bedrocks; c, pastures on siliceous bedrocks; d, shrubbed and reforested pastures) characterized by soil fertility, the type of bedrock (calcareous or acid substrates) and grazing management (e.g. extensive, degraded, abandoned pastures). These groups were divided into independent clusters which highlight some specific aspects of flora, not shared by other clusters, justifying different phytosociological considerations. The elaboration of each division confirmed as multivariate analysys (classification and ordination) has often kept together the vegetation formations from the same geographic district and representative of close vegetation types. To sum up, geography has played a very important effect on species composition; conditioning largely attributable to environmental factors specific to each location (climate, substrate, soil and altitude). But it seems likely that other factors, as phytogeography, played a main role. These results suggests a good correspondence between traditional expert-based associations recognized in the Italian Alps (Ziliotto et al. 2004; Cavallero et al. 2007) and an overall floristic variation within this study area.

The large number of vegetation types, subtypes, and species (more than 900 species were listed) found on grazing-lands of the Province of Trento is a consequence of a wide vegetation diversity, resulting in complex and unique land mosaics. Conservation of fragile environments and landscapes of the Alps and drawing of biodiversity action plans would take advantage from the large database resulting from the research, especially when endangered vegetation communities, rare biotopes or Site of Community Importance are concerned.

CHAPTER 3

PLANT DIVERSITY ALONG AN ELEVATION GRADIENT IN ALPINE PASTURES: EFFECTS OF DISTANCE FROM THE FARM CENTRE, TOPOGRAPHY AND MANAGEMENT

INTRODUCTION

Since the second half of the 20th century, changes in land use associated with the intensification of agriculture have been the major cause of losses in farmland biodiversity at local, regional and global scales (Norris 2008). Over the last few decades in many European countries, flat and more accessible areas have been managed more intensively, whereas hilly and mountain areas have been abandoned (MacDonald et al. 2000; Mottet et al. 2006; Tasser and Tappeiner 2002).

In the Italian Alps, summer pastures (mainly for cows and sheep) are still managed in traditional ways, which maintain important grassland habitats of many species, although the number of pastures has declined drastically over the past few decades. These summer farms consist mainly of grazed grasslands located around the centre of the farm (typically a stall). Summer farming created a landscape with large variation and strong gradients in grazing animal effects, which resulted in very distinct vegetation patterns (Vandvik and Birks 2002a, 2002b, 2004). Nitrophilous communities and productive manured grassland dominated the area immediately surrounding the stall. Away from farms, this heavily disturbed and manured vegetation gives way to extensive low-productive perennial grasslands (Vandvik and Birks 2004). A recent census of dairy farming in the Trento province revealed that only 300 of the 700 summer farms listed were actually managed (Provincia Autonoma di Trento, Dipartimento Agricoltura, unpublished data). As a result, the species composition of pastures below the tree line has been changing in favour of forest species with consequent reduction in biodiversity (Fischer and Wipf 2002). The grassland communities need to be maintained through periodic management interventions such as mowing and grazing in order to withhold tree and shrub encroachment (Rook et al. 2004).

Land use changes constitute a threat to the persistence of these grassland ecosystems (Dullinger et al. 2003; Spiegelberger et al. 2006). Therefore, it is very important to understand the mechanisms leading to the organization and distribution of these communities to preserve plant diversity and to develop effective agri-environment schemes, which can maintain and enhance biodiversity.

Environmental conditions and vegetation composition in the European Alps vary due to broad-scale factors such as altitude, precipitation or geographic location, reflecting different climatic conditions, and fine-scale site factors, like variation in slopes, aspects, and soils (Ellenberg, 1996; Wohlgemuth 1998; Moser et al. 2005; Marini et al. 2008b). Local grasslands factors have been demonstrated to be important drivers of plant diversity due to different management (Klimek et al. 2007; Raatikainen et al. 2007; Rudmann-Maure et al. 2008), topography (Sebastià 2004; Bennie et al. 2006) and soil properties (Critchley et al. 2002; Marini et al. 2007). Furthermore, Vandvik and Birks (2002b) found that the overriding floristic gradient at summer pastures in the mountain of western Norway was correlated with distance to farm gradient (from the centres of the farms to the surrounding vegetation). The functional interpretation suggested that the gradient is due to decreasing disturbance and increasing environmental stress caused by decreasing grazing and manure effects away from farms. Mountain environments provide interesting study areas to explore the relationship between environmental variables, management variables and species diversity along vertical gradients (elevation).

However, these factors and their relative importance for pasture are insufficiently known in the Alps, because only relatively few studies, most in the northern Alps (Muller et al. 2003; Kleijn and Müller-Schärer 2006) have examined the species richness and the species composition of this vegetation community. The specific objective of this study was to investigate and to interpret the patterns of species richness and species composition in pastures of the southern Alps in relation to local and regional factors. We hypothesized that (1) plant diversity varies in response to topography due to the highly variable alpine environment (Sebastia 2004; Pykälä et al. 2005; Bennie et al. 2006), and (2) variation in species composition and species richness depends strongly not only on grazing spatial gradient from the centres of the farms to the surrounding vegetation, but also on spatial distribution of the management practices within the study region (Vandvik 2002a, 2002b, 2004; Whitte et al. 2004; Klimek et al. 2007).

MATERIALS AND METHODS

Study site

The study was carried out in five administrative districts of the Trento Province in north-eastern Italy (Low Valsugana and Tesino, High Valsugana, Primiero, Fiemme Valley, and Fassa Valley) in 2008. The geology was heterogeneous with calcareous, siliceous bedrock and mixed sediments. The annual mean temperature was *c*. 6.5 °C at the minimum altitude (1286 m a.s.l.) and *c*. 1.0 °C at the maximum altitude (2382 m a.s.l.). The annual mean rainfall was *c*. 900 mm. All the selected pastures were located in the highlands, in an agricultural landscape characterized by coniferous forests or subalpine scrublands interspersed with grazed grassland, mountain hay meadows, and natural alpine and subalpine grasslands. Traditional summer pastures are grazed for two or three months during summer, mainly by cows and sheep, which are then moved back to the bottom of the valley for the rest of the year. The pastures are manured mostly in the form of animal urine and dung, and the area around the stall and other more accessible areas are supplied with farmyard manure.

Sampling

Summer farms sampling was conducted along an elevation gradient at eighteen sites ranging in elevation from 1286 to 2382 m a.s.l (Fig. 3.1). The elevation gradient was stratified into three ecoregions that differ in their elevation distribution and vegetation composition according to Odasso (2002): (1) treeless alpine (2000 – 2500 m a.s.l.), (2) conifer-dominated subalpine forest (1500 – 2000 m a.s.l.), (3) coniferous-deciduous montane forest (1000-1500 m a.s.l.). Information on summer farms distribution and digital elevation model of the Province, based on the data of the Agriculture Department of the Province of Trento, were analyzed in a GIS environment. All the summer farms, which of information was available in the five administrative districts (n = 145), were considered. Summer farms were clustered by ecoregion classification, as described previously. Six summer farms were randomly selected within each of the ecoregions. In total, eighteen summer farms were sampled (representing about 10% of the available summer farms in the five administrative districts).

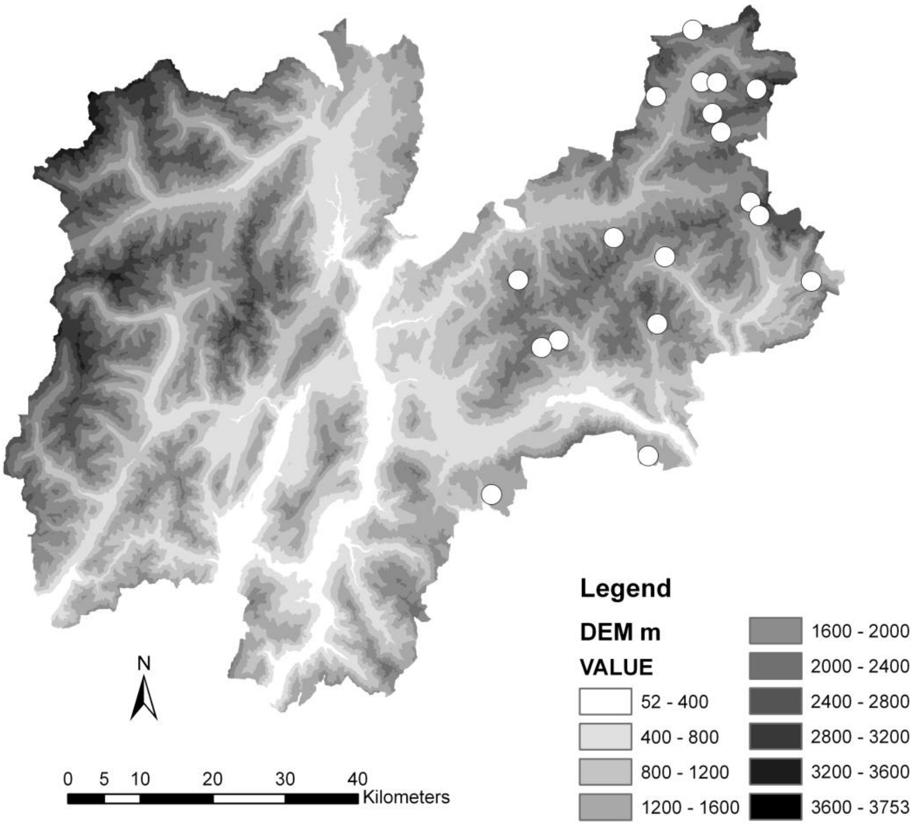


Fig. 3.1 Location of the study area in Province of Trento (NE Italy), showing the sampled summer farms (*n* = 18). The Trento Province (World Geodetic System 1984: 45°43.8’–46°28.3’ N, 10°31.9’–11°53.4’ E) was represented by digital elevation model (SIAT, Servizio Urbanistica e Tutela del Territorio, Provincia Autonoma di Trento, cell size 25 · 25 m) .

Considering that animals graze freely during the day and are gathered at night in the farm centre (barn, milking shed, or other assembly point for the animals), the spatial gradient extending from farm centre to surrounding vegetation was assumed – a priori – to parallel a gradient of decreasing animal influence on vegetation. In July and August 2008, 157 plots, each measuring 5 m × 5 m, were placed subjectively in order to sample the major floristic variation at each farm, including heavily grazed, trampled, and manured vegetation (around the farm centre), less intensively utilized grasslands, and surrounding heaths (marginal areas).

Species composition was recorded in each of the 157 plots using the nomenclature described by Äeschimann et al. (2004). Within each main plot, three subplots, each measuring 1 m × 1 m, were randomly located and the percentage cover of each species was estimated. Plant species richness was estimated as the total number of species found in each main plot. Species composition was calculated as the mean percentage cover of each species of the three subplots.

Explanatory variables

For each plot, three local environmental variables (E) were defined: slope (SLOPE), plot distance from the farm centre (DIST), and soil depth (DSOIL). Slope was calculated in SAGA GIS Version 2.0.3 (available at http://www.saga-gis.org) using a digital elevation model with a cell size of 10 m × 10 m. Plot distance from the farm centre was used as a surrogate for grazing pressure. For each main plot, soil depth was determined as the mean depth of three probes, one in each 1m × 1m subplot. Three regional parameters were defined: altitude, bedrock types and grazing intensity. Altitude (ALT) was calculated using a digital elevation model with a resolution of 10 × 10 m. The bedrock variables (BED) were obtained from a geological map of the Province (Bosellini et. al. 1999). The bedrock types were grouped into two qualitative classes: calcareous bedrock (CALC) and acid bedrock (ACID). ALT and BED were retrieved for each plot, while for each farm by averaging these variables within the farms (for BED variable in each farm was found or just CALC or just ACID). Moreover, for each farm was estimated the grazing intensity considering the average stock density, expressed in livestock units (LU), divided by farm size, in order to standardise this index between farms(Table 3.1).

Table 3.1 Descriptive statistics of the quantitative explanatory variables used in the analysis of 157 pastures of the Italian Alps.

Variable name and explanation		Unit	Mean	Min	Max
Local factors (field scale)					
SLOPE	Slope angle	Degree (°)	14.72	0.01	34.49
DIST	Distance to fam centre	m	373.61	11.50	1295.40
DSOIL	Soil depth	cm	15.14	2.00	50.00
Regional factors (farm scale)					
ALT	Mean altitude	m a.s.l.	1820	1358	2250
GRAZ	Grazing intensity	LU ha^{-1}	0.87	0.52	1.41

Data analysis

Prior to analysis, the data on species composition were Hellinger-transformed (Legendre and Gallagher 2001) to express species abundance as a square-root-transformed proportionate abundance in each sampling. This transformation reduces the weight of the most abundant species in the analysis. Furthermore, species richness was square-root transformed to achieve normal distribution and homogeneity of variance of the residuals (Quinn and Keough 2002).

Local parameters were tested in a multiple regression model to identify the most important factors controlling species richness and species composition at the field scale. Given that multicollinearity among explanatory variables can hamper the identification of the most causal variables (MacNally 2000), the Pearson correlation matrix was performed. In the case of highly correlated variables ($r > 0.60$), only one of them was used to avoid multicollinearity; no high collinearity between variables was detected (see Appendix B). Forward selection of predictor variables was run to select those variables that contributed significantly ($P \leq 0.05$ after 999 random permutations) to explanation of variation in species richness and species composition (following the procedure recommended by Blanchet et al. 2008). The analysis was performed using the function ‘forward.sel’ in the ‘Packfor’ package in R (available at https://r-forge.r-project.org/projects/sedar). Finally, the models were validated by the analysis of residuals, to assess homogeneity and to verify normality (Quinn and Keough 2002). No transformation of predictor variables was necessary.

The analysis of regional parameters (ALT, BED and GRAZ) was performed at farm scale. As response variables, were used i) total number of species for each farm and ii) vegetation composition, as presence-absence data, for each farm. ALT and BED effects on species richness were tested by linear mixed model (ALT and BED were fixed factors, while farms were added as a random factor), while GRAZ by simple regression model. Species composition variation was presented by RDA ordination. Given the low number of replications (18 farms), regional parameters were analyzed in order to verify an effect on species richness and specie composition and were not tested in multiple regression model to determine the relative importance of the variables.

Finally, the interaction between local and regional factors was tested at the field scale; the effects of DIST and the SLOPE on species richness and species composition were analyzed at various summer farms altitude distribution and bedrock types. Local and regional parameters were reclassified in categorical variables. We defined three class of altitude: i) 1000-1500 m a.s.l., ii) 1500-2000 m a.s.l., iii) 2000-2500 m a.s.l.; two class of bedrock types: i) calcareous, ii) acid; three class of grazing intensity: i) 0.5-0.8 LU ha^{-1}, ii) 0.8-1.1 LU ha^{-1}, iii) 1.1-1.4 LU ha^{-1}; three class of distance from the farm centre: i) 0-250 m, ii) 250-500 m, iii) 500-1000 m; and three class of slope: i) 0-10°, ii) 10-20°, iii) 20-35°. Each plot was grouped following the new categorical classification of local and regional parameters. The main effect (local and regional parameters) and their interaction (local × regional) were tested for significance; the local factors were analyzed separately for each regional factor. Linear mixed models was applied to species richness (local and regional parameters were a fixed factor, while farms were added as a random factor). Species composition was tested by multivariate analysis of variance following the procedure recommended by ter Braak and Šmilauer 2002. Categorical variables were coded as dummy variables, while farm identifiers were treated as block factor and used as covariates in the analysis.

Linear mixed models were conducted using the 'nlme' package (version 3.1-96; Pinheiro et al. 2009) implemented in R version 2.10.1 (R Development Core Team 2009), where multivariate analysis of variance and RDA ordination using CANOCO Version 4.5 (ter Braak and Šmilauer 2002).

Table 3.2 Summary of forward selection of the local variables in the multiple linear regression models of plant species richness and composition for local environment at the field scale (SLOPE, slope angle; DIST, distance from the farm centre; DSOIL, soil depth).

				Model			
	F	*P*	R^2	Adj R^2	d.f.	*F*	*P*
Species richness							
SLOPE (+)	26.3	0.001	0.145	**0.139**	1,155	26.3	<0.001
Species composition							
DIST	5.3	0.001	0.033	**0.063**	3,153	4.3	<0.001
SLOPE	4.3	0.001	0.026				
DSOIL	3.7	0.001	0.022				

The amount of adjusted coefficient of multiple determination (Adj R^2) is given for each model following the procedure of Blanchet et al. (2008). The direction of the relations (– or +), the *F* statistic and the *P*-values (Monte Carlo Permutation test, n = 999) for significant variables and for each model ($P < 0.05$) are presented.

RESULTS

A total of 356 species of vascular plants were found in the 157 plots. The species comprised 93 monocotyledons and 263 dicotyledons. The mean species richness was 34 per 25 m²; the minimum number was 15 and the maximum was 58.

The results of the multiple regression models testing local factors on plot species richness and plot species composition are reported in Table 3.2. Species richness model included only SLOPE (positively related) and explained 14% of the total variation. Species composition model, consisting of linear terms of DIST, SLOPE, and DSOIL, explained 6.3% of the variation. The response of 21 species with a cumulative fit above 10% on the first two axes is presented as an RDA biplot (Fig. 3.3a).

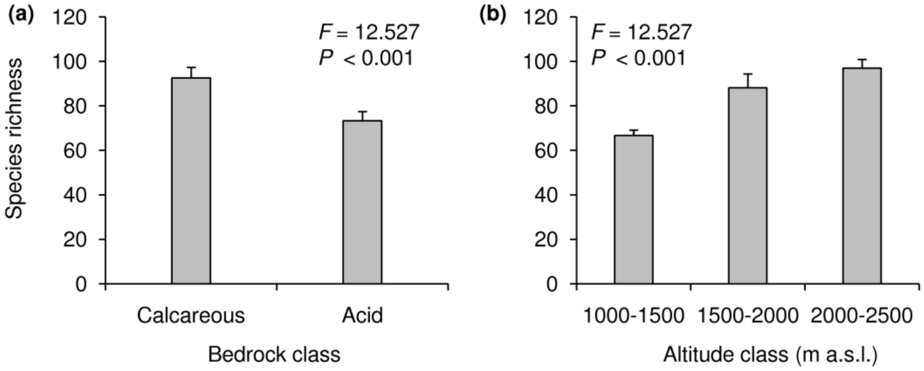


Fig. 3.2 Differences in farm species richness between (a) bedrock class and (b) altitude class. *F* statistic and the *P*-values from linear mixed model considering bedrock and altitude parameters as fixed factor, while farms as a random factor. Analysis were performed on square-root transformed data.

The first axis accounted for 4% of the total variation and showed a gradient of the DIST and SLOPE. Pastures located near the farm centre and in plain were dominated by *Deschampsia caespitosa*, *Plantago major* subsp. *major*, *Urtica dioica*, *Rumex alpinus*, *Trifolium repens* subsp. *repens, Poa pratensis* and *Alchemilla xanthochlora*, whereas *Nardus stricta*, *Avenella flexuosa, Geum montanum*, *Arnica montana*, *Carex sempervirens*, *Festuca varia*, *Elyna myosuroides*, and *Trifolium pratense* subsp. *nivale* occurred mainly on sites farther away from the farm centre and on steeper sites. The second axis accounted for 2% of the total variation and was determined by the DSOIL. *Festuca nigrescens* and *Poa alpina* were more common in deeper soil. Moreover, community dominated by *Nardion strictae* phytosociological alliance seem to be positively related to DSOIL.

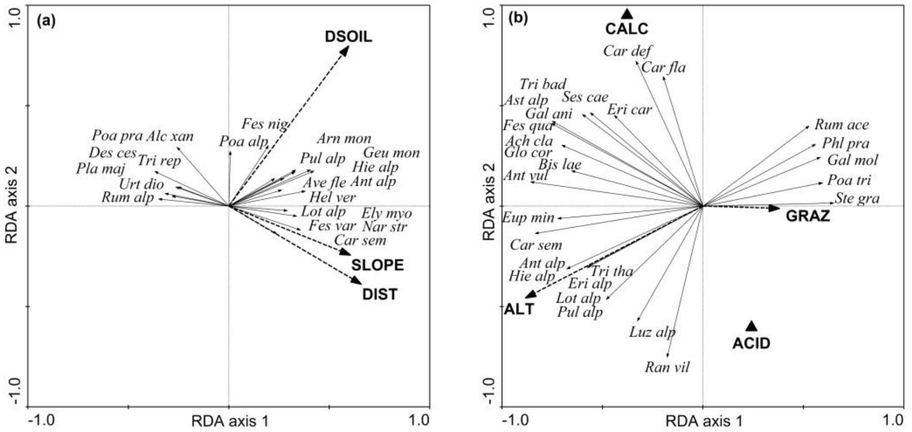


Fig. 3.3 Ordination biplots based on redundancy analysis (RDA) between (a) plots species composition and local explanatory variables and between (b) farms species composition and regional explanatory variables. Vascular plant species are represented by solid-line arrows, the proximity of which indicates occurrence in similar environmental conditions. Numeric explanatory variables are represented by dotted-line arrows and nominal explanatory variables by triangles, which point toward increasing values of that variable. Their length (numeric variables) or distance (nominal variables) is directly proportional to their importance in influencing plant community structure. A smaller angle between the explanatory variables and the ordination axis indicates greater influence of the variable on the environmental gradient. The projected location of each species along each explanatory variable indicates how important the environmental variable is to the abundance and distribution of the species. Only plant species (n= 21, plot composition; n= 27, farms composition) with a cumulative fit above 15% on the first two axes are shown. Abbreviations: SLOPE, slope angle; DIST, distance from the farm centre; DSOIL, soil depth; ALT, mean altitude; CALC, calcareous bedrock; ACID, acid bedrock; GRAZ, grazing intensity. Species names abbreviations: Ach cla, *Achillea clavenae*; Alc xan, *Alchemilla xanthochlora*; Ant alp, *Anthoxanthum alpinum*; Ant vul, *Anthyllis vulneraria* subsp. *alpestris*; Arn mon, *Arnica montana*; Ast alp, *Aster alpinus*; Ave fle, *Avenella flexuosa*; Bis lae, *Biscutella laevigata* subsp. *laevigata*; Car def, *Carduus defloratus* subsp. *tridentinus*; Car fla, *Carex flacca*; Car sem, *Carex sempervirens*; Des ces, *Deschampsia cespitosa*; Ely myo, *Elyna myosuroides*; Eri alp, *Erigeron alpinus*; Eri car, *Erica carnea*; Eup min, *Euphrasia minima*; Fes nig, *Festuca nigrescens*; Fes qua, *Festuca quadriflora*; Fes var, *Festuca varia*; Gal ani, *Galium anisophyllon*; Gal mol, *Galium mollugo*; Geu mon, *Geum montanum*; Glo cor, *Globularia cordifolia*; Hel ver, *Helictotrichon versicolor*; Hie alp, *Hieracium alpicola*; Lot alp, *Lotus alpinus*; Luz alp, *Luzula alpina*; Nar str, *Nardus stricta*; Phl pra, *Phleum pratense*; Pla maj, *Plantago major* subsp. *major*; Poa alp, *Poa alpina*; Poa pra, *Poa pratensis*; Poa tri, *Poa trivialis* subsp. *trivialis*; Pul alp, *Pulsatilla alpina* subsp. *apiifolia*; Ran vil, *Ranunculus villarsii*; Rum ace, *Rumex acetosa*; Rum alp, *Rumex alpinus*; Ses cae, *Sesleria caerulea*; Ste gra, *Stellaria graminea*; Tri bad, *Trifolium badium*; Tri rep, *Trifolium repens* subsp. *repens*; Tri tha, *Trifolium thalii*; Urt dio; *Urtica dioica*.

Table 3.3 Results of the interaction analysis between local (DIST, distance from the farm centre; SLOPE, slope angle) and regional factors (BED, bedrock class; ALT, altitude class) at the field scale. Species richness was tested by linear mixed model, while species richness by multivariate analysis of variance considering local and regional parameters as fixed factor, while farms as a random factor.

		Species richness[a]		Species composition	
Source of variation	df	*F*	*P*	*F*	*P*
BED	1	12.595	**0.003**	5.200	**0.001**
DIST	2	1.460	0.236	2.775	**0.001**
BED × DIST	2	0.872	0.421	1.098	0.307
ALT	2	2.0866	0.1587	7.581	**0.001**
DIST	2	1.9696	0.1436	3.149	**0.001**
ALT × DIST	4	0.9989	0.4106	1.117	0.191
BED	1	17.068	**0.001**	5.830	**0.001**
SLOPE	2	11.393	**<0.001**	2.547	**0.001**
BED × SLOPE	2	0.756	0.472	1.404	0.055
ALT	2	1.8519	0.1911	6.373	**0.001**
SLOPE	2	7.5871	**0.007**	1.473	**0.037**
ALT × SLOPE	4	0.0115	0.9886	1.073	0.276

[a] Response variable was square-root transformed.

The analysis of regional factors at farm scale, showed a significant effect of ALT and BED on species richness (Fig 3.2). Farms located at lower altitude (1000-1500 m a.s.l.) supported lower species richness (66.7 ± 6.1), while the alpine farms (2000-2500 m a.s.l.) were those with the greatest number of species (97.0 ± 9.5). Moreover, farms located on calcareous bedrock showed greater species richness (92.5 ± 12.0) than those placed on acid bedrock (73.3 ± 15.2). Considering the rate of grazing intensity of each farm, species richness showed a humped relationship with stock density (Fig. 6). The results of relations between fams species composition and regional factors are presented as an RDA biplot (Fig 3.3b). The first axis (17% of the total variance) showed a gradient of increasing GRAZ and increasing ALT. Farms managed more intensively were dominated by *Stellaria graminea*, *Phleum pratense*, *Rumex acetosa*, *Poa trivialis* subsp. *trivialis* and *Galium mollugo*, whereas *Lotus alpinus*, *Trifolium thalii*, *Hieracium alpinum*, *Erigeron alpinus*, *Pulsatilla alpina* subsp. *apiifolia*, *Anthyllis vulneraria* subsp. *alpestris* were more common on alpine pastures. The second axis (9% of the total variance) distinguished CALC than those ACIDS. Species of *Seslerion variae* phytosociological alliance (*Sesleria caereluea*, *Cardus defloratus*, *Aster alpinus*, *Festuca quadriflora*, *Achillea clavenae* and *Galium anisophyllon*) dominated calcareous bedrocks.

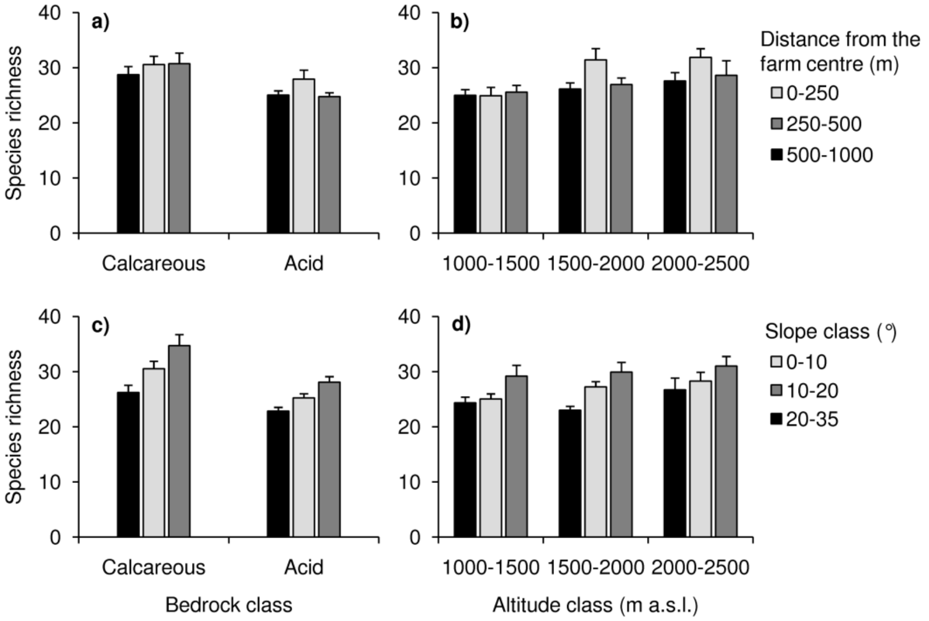


Fig. 3.4 Mean species richness in relation to the (a, c) bedrock, (b, d) altitude classes and the (a, b) distance from the farm centre classes and the (c, d) slopes classes Standard errors are also reported**.**

The results of interaction analysis between local and regional factors at the field scale on species richness and specie composition were reported in Table 3.3. The interaction terms were not significant in all the analysis. A positive effect of SLOPE and CALC were found on species richness (Fig 3.4). The main effects of DIST and ALT on species richness were not significant, although seemed to be a humped relationship with DIST (Fig. 3.4a,b). The main effects of local and regional parameters on species composition were significant (Table 3.3).

DISCUSSION

The results suggest that plant species richness and species composition responded in a different way to the considered determinants. In line with our first hypothesis, species diversity was affected by topography and depended mainly on slope angle. The positive relationship between increasing slope and species diversity was found by several authors (Pykälä et al. 2005; Bennie et al. 2006; Klimek et al. 2007; Marini et al. 2008a, 2009). The plant communities observed on flat lands were dominated by productive and competitive species, whereas steeper pastures were characterized by a greater number of small stress-tolerant species. Steeper slopes are buffered to some extent against invasion by more competitive species, probably due to edaphic factors (low soil nutrient availability) and disturbance factors (substrate movement, snow movement) (Bennie et al. 2006). Topography is a main driver due to the strong effect of altitude and slope on temperature, and consequently on the length of the growing season, confirming that the occurrence of many grasslands species is governed by topographic characteristics (Sebastià 2004; Bennie et al. 2006; Marini et al. 2007). Moreover, the significant effect of altitude on species composition and farms species richness (Fig. 3.2b and Fig. 3.3b) was also caused by different field management practices between the pastures located on high altitude compared to the low-altitude ones. The species composition ordination (Fig. 3.22b) showed not only replacement of montane by subalpine species with increasing altitude, but also confirmed that the elevation gradient represented also a gradient of management intensity. The negative correlation between grazing intensity and average altitude of each farms (Pearson correlation test: r = -0.50, df = 16, p = 0.033; see Appendix B) confirms this hypothesis.

According to our second hypothesis, species diversity was affected not only by topography, but also by change on grazing spatial gradient. Distance from the farm centre (used as a proxy for grazing pressure) showed an important effect on species composition. In the marginal sites, where grazing levels were very low or where sites were left ungrazed, succession proceeded to floristically impoverished community dominated by *Nardion strictae* phytosociological alliance. Similar relationship was found by several studies (Jewell et al. 2005; Badia el al. 2008; Niedrist et al. 2009).

The dominance of *Nardion strictae* species in the marginal areas was probably caused by the low soil nutrient availability. As demonstrated by Güsewell et al. (2005) and Klaudisová et al. (2009), the increase phosphorous availability in the soil tends to decrease the competitive ability of *Nardus stricta*. Grazing spatial gradient had not significant effect on plot species richness, although seemed to be a humped relationship with distance from the farm centre, mainly on acid bedrocks and in subalpine and alpine pastures (Fig 3.4a,b). Pastures located near the farm centre (0-250 m), where the grazing intensity was high and marginal sites (500-1000 m), where grazing levels were very low or abandoned species richness was lower than intermediate pastures (250-500 m). Probably, in these sites the intermediate grazing level contributed to the maintenance of plant diversity by reducing the abundance of competitive dominant species (Collins et al. 1998; Olff and Ritchie 1998). This finding supports the Intermediate Disturbance Hypothesis according to which the diversity is high when disturbances occur at an intermediate frequency or with intermediate intensity (Grime 1973; Connell 1978)

Even though the low number of farm replications available to assess the relative importance of regional parameters on species diversity, it seemed to be a significant effect of spatial distribution of the management practices within the study region. The results probably reflect that topographic related site characteristics determined the spatial distribution of the land use within the study region (White et al. 2004; Klimek et al. 2007; Rudmann-Maure et al. 2008). As discussed above, farms located on high altitude showed lower grazing intensity and higher species richness than farms located on low altitude. Mottet et al. (2006) in the Pyrenees and Kampmann et al. 2008 in the Swiss Alps identified slope and elevation as driving forces in decision making for management type, and good accessibility of parcels as a prerequisite for maintaining pastoral management, and preventing abandonment. Higher elevations imply a lower economic yield potential of sites (i.e. shorter growing season, drier soil conditions and more difficulties in management). This can be associated to a lower management pressure, which allows for higher species diversity. High species richness at these sites is therefore a result of both the ecological potential and the traditional low input farming (Bakker 1989;

Kruess and Tscharntke 2002; Kampmann et al. 2008). Moreover, the humped relationship between farm species richness and grazing intensity (Fig. 3.4) highlighted the negative effect of low stocking rate on species diversity. Probably, in these farms marginal sites have been abandoned, that results in a decline of species richness at the farm scale. This pattern could explain the lower number of species found on marginal sites (500-1000 m) in subalpine and alpine pastures, as mentioned above. Dullinger et al. (2003) demonstrated an unequivocal decrease of vascular plant species diversity as a long-term trend of pasture abandonment at the landscape scale. Simultaneously a homogenization of the vegetation cover, that was a reduction of plant community diversity, occurred.

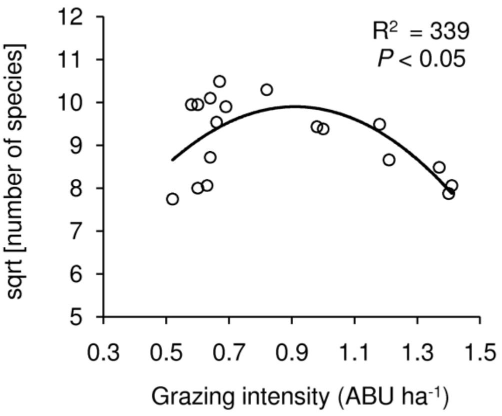


Fig. 3.5 Differences in farm species richness between (a) bedrock class and (b) altitude class. *F* statistic and the *P*-values from linear mixed model considering bedrock and altitude parameters as fixed factor, while farms as a random factor. Analysis were performed on square-root transformed data.

The analysis also highlighted the importance of underlying bedrock in controlling species diversity (Fig 3.2b and Fig. 3.3a). The occurrence of calcareous substrates was of major importance in enhancing species richness, supporting the findings of other studies in the European Alps (Wohlgemuth 1998; Moser et al. 2005; Marini et al. 2008b). Overall, the Alpine flora contains more species restricted to calcareous than acid bedrock (Ewald 2003). Marini et al. (2008b) resumed this pattern as the result of different processes such as: (1) species–area relationships caused by different substrate rejuvenation and range contraction between calcareous and siliceous bedrock caused by glaciations (Ewald 2003); (2) speciation and extinction dynamics related to the prevalence of basic substrates in Europe (Grime 2001); or (3) other potential factors confounding with calcareous bedrock (Wohlgemuth and Gigon 2003).

In conclusion, the patterns of species richness and species composition found in alpine pastures result from the interaction of topography and management factors operating at different spatial scales. The results indicate that at small scales (within farms) species richness is mainly determined by slope, while specie composition is controlled by distance from the farm centre (used as a proxy for grazing pressure) as well as slope. At large scale (between farms), despite the low number of replication, was observed a key role of grazing intensity and bedrock types on species diversity patterns. Our results indicate that the identification of appropriate stocking rates appears to be the most promising approach to conserve the high biodiversity of alpine pastures, as both intensification and abandonment changed species composition and reduced plant species diversity (Spiegelberger et al. 2006).

CHAPTER 4

ADDITIVE PARTITIONING OF PLANT DIVERSITY AND FUNCTIONAL DIVERSITY WITH RESPECT TO GRASSLAND MANAGEMENT REGIME, FERTILISATION AND ABIOTIC FACTORS

INTRODUCTION

It is widely accepted that species richness in a community is determined by local processes such as resource competition, disturbance regime and biotic interactions (Collins et al. 2002; Ricklefs 1987). Moreover, there is evidence that the community structure and its dynamics are governed by the regional species pool and dispersal limitations (Pärtel et al. 1996; Poschlod et al. 2005). Management regimes like mowing and livestock grazing affect plant species diversity in grasslands, especially by their intensity and continuity (Bakker et al.2002; Smith et al.1996). Recent studies suggest that low-to-moderate disturbances due to grazing animals may promote species richness by creating heterogeneity in soil and sward structure, and by re-allocation of nutrients (Adler et al. 2001; Collins et al. 1998; Rook et al. 2004). In addition, vascular plant species diversity in grasslands is related to abiotic environmental factors including soil and topography-related physical attributes (Bennie et al. 2006; Critchley et al. 2002).

The partitioning of biodiversity into different spatial components is critical to understand processes underlying species distributions and diversity turnover (Magurran 2004; Ackerly & Cornwell 2007; Prinzing et al. 2008; de Bello et al. 2009). In particular, proper management of ecosystems requires that we understand the processes by which β-diversity (i.e. the diversity across habitats or communities) is generated and maintained (Legendre et al. 2005). Several indices and mathematical frameworks have been developed for these purposes (Lande 1996; Veech et al. 2002; Crist & Veech 2006), making it possible to answer different ecological questions and unavoidably producing little consensus among methods (Koleff et al. 2003). Overall, it is widely accepted that the total diversity of a region (γ-diversity) can be partitioned into within-community (α-diversity) and among-communities (β-diversity; Whittaker 1975; Magurran 2004 and references therein) components. Partitioning of diversity could then be additive (e.g. $\gamma = \alpha + \beta$) or multiplicative ($\gamma = \alpha \times \beta$), depending on the models and mathematical indices used (Veech et al. 2002; Ricotta 2005a; Jost 2007; Jost et al. 2010).

Functional trait diversity (FD, the extent of trait differences in a unit of study; Tilman 2001; Petchey & Gaston 2002; Wilson 2007) is one of the most relevant components of biodiversity affecting ecosystem functioning (Díaz & Cabido 2001; Hooper et al. 2005; Mason et al. 2005; Díaz et al. 2007). Community assembly theory suggests that several forces influence FD, particularly species interactions and habitat filtering (Cornwell et al. 2006; Grime 2006). The relative effects of these processes on trait diversity have traditionally been assessed within communities (Stubbs & Wilson 2004; Fukami et al. 2005; Cornwell et al. 2006; de Bello et al. 2006; Grime 2006; Wilson 2007; Pillar et al. 2009), whereas these effects also vary across spatial scales and communities. Community assembly results from forces operating at different spatial scales (Díaz et al. 1998; Pierce et al. 2007) so that trait diversity among species occurs in a given region at different levels, e.g. within community and among communities (MacArthur & Levins 1967; Thompson et al. 1996; Westoby et al. 2002).

The within-community FD describes trait diversity among species coexisting within a given community. Species interactions are supposed to increase the within-community FD, i.e. by limiting the similarity among coexisting species traits (trait divergence; Chesson et al. 2004; Stubbs & Wilson 2004; Hooper et al. 2005). On the other hand, habitat filtering reduces within-community trait differentiation, i.e. by selecting species with shared ecological tolerances from the regional species pool (trait convergence; Weiher & Keddy 1995; Díaz et al. 1998; Garnier et al. 2004; Fukami et al. 2005; Bertiller et al. 2006; Cornwell et al. 2006; Grime 2006). These assembly forces, however, also exert pressure over the among-communities FD, i.e. the trait diversity among species from different communities. Although there have been attempts to calculate among-community components of FD (Westoby et al. 2002), we still need formal frameworks to estimate and assess the relative effects of both within- and among-community trait differentiation.

Understanding spatial patterns of FD is important because it reveals the operation of non-neutral community assembly rules (Weiher & Keddy 1995; Stubbs & Wilson 2004; Cornwell et al. 2006; Mason et al. 2007; Mouillot et al. 2007; Petchey et al. 2007). If local assemblages are composed of random sets of species, their FD values will tend to be distributed according to null models. Nonrandom distributions of species traits indicate that processes such as limiting similarity or environmental filtering structure local assemblages (Mason et al. 2007; Mouillot et al. 2007; Petchey et al. 2007). Therefore, by comparing observed patterns in FD to null expectations, it is possible to test different hypotheses about community assembly that determine trait convergence and divergence among species. Nevertheless, the spatial partitioning of FD is normally not taken into account by such null model approaches. The assessment of within community FD alone only allows for the existence of either trait convergence or trait divergence (see e.g. Fig. 1 in Petchey et al. 2007).

As plant species distributions in a landscape are the result of processes operating at both local and regional spatial scales (Collins et al. 2002; Huston 1999; Ricklefs 1987), it is essential to quantify species diversity at multiple scales. Using the approach of additive partitioning (Lande 1996; Veech et al. 2002), species diversity is partitioned into alpha and beta components at user-defined spatial scales.

In this study, we collected plant species data in summer farms of Province of Trento along an elevation gradient. Simpson index of diversity and functional diversity, measured as functional dispersion (Lalibertè and Legendre 2010), were quantified for each plot and farm. Hierarchically nested sampling design was applied and included 9 vegetation plots within each of 8 summer farms belonging to three ecoregions (1) 1000-1500 m a.s.l.; 2) 1500-2000 m a.s.l.; 3) 2000-2500 m a.s.l.). At the local scale, additive diversity components was quantified from 216 vegetation plots (72 for each ecoregion, respectively) within 24 summer farms, and at the regional scale from 24 summer farms (8 farms for each ecoregion) within the study region. To gain insight into the processes that may affect species diversity and functional diversity in alpine pastures, the observed local patterns of additive species diversity components (α-, β-, γ-) were analysed with respect to altitude, landscape, topographic hetereogeneity, bedrock type and grazing intensity.

MATERIALS AND METHODS

Study area

The study area was the Province of Trento (north-east Italy), an area of he study area was the Province of Trento (north-east Italy), an area of 6207 km^2 (WGS84: N 45°43.8′–46°28.3′, E 10°31.9′–11°53.4′) on the southern border of the European Alps. The elevation range varies from 66 to 3769 m a.s.l. The local climate depends primarily on altitude, and only secondarily on latitude, varying from sub-Mediterranean conditions in the southern and central parts to continental conditions in the inner valleys. The annual rainfall averages c. 1000 mm year^{-1} and the annual mean temperature is c. 6.5°C (Marini et al. 2008). All the selected pastures were located in the highlands, in an agricultural landscape characterized by coniferous forests or subalpine scrublands interspersed with grazing grasslands, mountain hay meadows, and alpine and subalpine grasslands. Traditional summer farming in the areas follows the “alpeggio” system: pastures are grazed for two or three months during summer, mainly by cows and sheep, which are then moved back to the bottom of the valley for rest of the year.

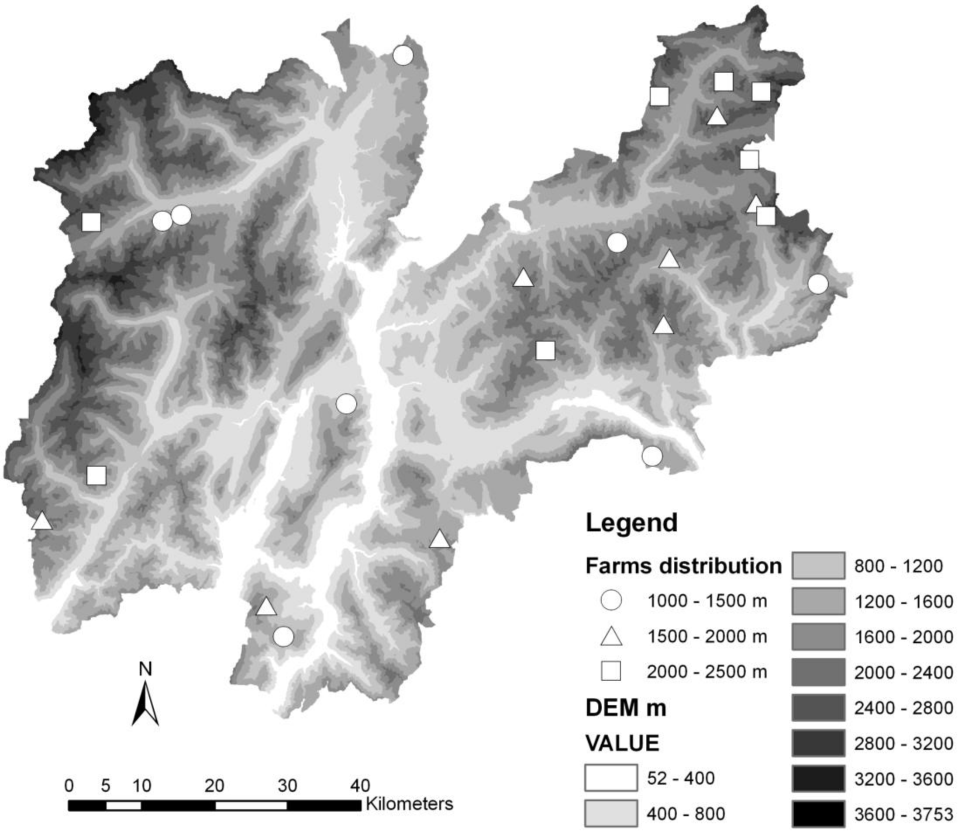


Fig. 4.1 Location of the study area in Province of Trento (NE Italy), showing the summer farms (*n* = 24) grouped by ecoregions. The Trento Province (World Geodetic System 1984: 45°43.8’–46°28.3’ N, 10°31.9’–11°53.4’ E) was represented by digital elevation model (SIAT, Servizio Urbanistica e Tutela del Territorio, Provincia Autonoma di Trento, cell size 25 · 25 m) .

Sampling design

Summer farms sampling was conducted along an elevation gradient at twenty-four sites ranging in elevation from 962 to 2313 m a.s.l (Fig. 4.1). The elevation gradient was stratified into three ecoregions that differ in their elevation distribution and vegetation composition according to Odasso (2002): (1) treeless alpine (2000 – 2500 m a.s.l.), (2) conifer-dominated subalpine forest (1500 – 2000 m a.s.l.), (3) coniferous-deciduous montane forest (1000-1500 m a.s.l.). Twenty-four summer farming were nested within each of the ecoregions. Within each summer farming nine 5 × 5 m plots were placed randomly in order to sample the major floristic diversity and grazing intensity of each farm. The plots traversed the complete gradient from the centre of the farm to the border between the pastures and the surrounding heath or woodland vegetation and from flat to hilly areas. In total, 216 plots were surveyed during summer of 2008 and 2009. In each vegetation plot, all the vascular plant species were identified to species level using the nomenclature described by Äeschimann et al. (2004). Plant species richness was estimated as the total number of species found in each 5 × 5 m plot.

Table 4.1 Traits and their attributes used in the analyses.

N	**Traits**	**Code**	**Data type**	**States**
1	Life span	LS	ordinal	1. annual; 2. annual-biennial; 3. biennial; 4. annual-biennial-perennial; 5. perennial
2	Life form	LF	ordinal	1. therophyte; 2. hydrophyte; 3. geophyte; 4. hemicryptophyte; 5. chamaephyte; 6. phanerophyte
3	Grime's CSR strategy	GRIME	ordinal	1. C; 2. S; 3. R; 4.CS; 5. CR; 6. SR; 7. CSR
4	Average height	HEIGHT	quantitative	cm
5	Leaf mass	LM	quantitative	mg
6	Leaf dry matter content	LMDC	quantitative	mg g^{-1}
7	Specific leaf area	SLA	quantitative	mm^2 mg^{-1}
8	Clonality	CLO	binary	
9	Reproduction mode	REPR	ordinal	1. vegetative; 2. vegetative and by seed; 3. by seed
10	Breeding system	BREED	ordinal	1. autogamous; 2. facultative autogamus; 3. allogamous; 4. facultative allogamous; 5. mixed
11	Flowering duration	FLOW	quantitative	no. of months
12	Pollen vector	POL	ordinal	1. self; 2. wind; 3. insects
13	Seed mass	SM	quantitative	mg

Functional traits

Species were characterized by their basic traits (e.g. life form or average height) as well as composite traits (such as Grime's CSR strategy). Thirteen quantitative, ordinal and binary traits were selected (Table X). Traits were compiled from existing local floras (Äeschiman et al. 2004) and from other published sources (Kleyer et. al. 2008; Klotz et. al. 2002; Liu et al. 2008) (Table 4.1).

Explanatory variables

Altitude (ALT) was calculated in ArcGIS 9.2 (ESRI, Redland, CA) using a digital elevation model with a cell size of 10 m × 10 m. Temperature (TEMP) was retrieved from continuous raster-based climatic maps with a resolution of 100 x 100 m (1990-99). The climatic data were interpolated using 64 climatic stations located throughout the province (Sboarina & Cescatti, 2004). The mean value was obtained by averaging the values within each summer farming surface. Due to the high collinearity between ALT and TEMP (Table 4.2), only ALT was included in the further analysis. To provide measures of environmental heterogeneity within each summer farms, we derived a series of indices, as follows: topographic heterogeneity – I calculated the elevation range (ALT_H) and the standard deviation of slope (SLO_H). Topographic heterogeneity indices were highly correlated between them (Table X) and to avoid multicollinearity I used only SLO_H in the models. At the landscape scale, we quantified the area of land-use classes surrounding each grassland site. Landscape composition variables were measured by calculating a circular buffer with a 500-m radius around the geographical centre of each plot. The land-cover variables were derived from a vector-based land-use map (SIAT, Servizio Urbanistica e Tutela del Territorio, Trento, Italy). We defined the following two land-use classes: (1) grassland (GRA) consisted of permanent mown meadows or pastures; (2) forest (FOR) included closed deciduous and coniferous forests; and (3) bare rock (ROCK) consisted of scree, cliffs and rocks outcrops. The vector-based data were converted to a raster model with a cell size of 25 x 25 m. Then, we calculated the proportion of the different land-use classes within each buffer using ArcGIS 9.2 (ESRI, Redland, CA). Again, to avoid multicollinearity was reduced the number of land-cover variables; since, GRA was highly correlated with FOR, the former variable was not used in subsequent analyses. Finally, bedrock variables were retrieved from the geological map (1:200.000) of the province. We classified each bedrock type into two main classes: (1) calcareous bedrock (CAL), and (2) acid bedrock (ACI). Due to high collinearity between these bedrock types, only CAL was included in the further analysis. The mean value for water-energy, environmental heterogeneity and bedrock type variables was obtained by averaging the values within each summer farming surface, whereas farm landscape composition was obtained by averaging the land-cover values of each buffer around the geographical centre of each plot within the farm. Moreover, for each farm was estimated the grazing intensity (GRAZ) considering the average stock density, expressed in livestock units (LU), divided by farm size, in order to standardise this index between farms.

Table 4.2 Descriptive statistics of the quantitative explanatory variables used in the analysis of 24 summer farms ("*malghe*")

Variable name and explanation[a]		Unit	Mean	Min	Max
ALT	Average altitude	m	1732.4	962	2313
CAL	Area covered by calcareous bedrock	%	49.8	0	100
[ACID]	Area covered by acid bedrock	%	40.7	0	100
FOR	Area covered by forest	%	46.9	0	91.4
[GRA]	Area covered by grasslands	%	39.3	8.0	92.8
ROCK	Area covered by bare rock	%	5.3	0	39.0
[TEM]	Mean annual temperature	°C	4.50	1.17	8.45
[ALT_H]	Altitude range	m	193	79	435
SLO_H	Slope heterogeneity (standard deviation)	Degree (°)	5.98	3.66	10.56
GRAZ	Grazing intensity	LU ha^{-1}	0.80	0.46	1.90

[a] Intercorrelated variables excluded after the analysis of the Pearson correlation matrix are presented in square parentheses.

Simpson diversity and functional diversity

Simpson index of diversity (D) was calculated for each 5 × 5 m plot. This index was applied to measure components of the species diversity and represents the probability that two individuals randomly selected from a sample will belong to different species:

$$D = 1 - \sum_{i=1}^{S} p_i^2$$

where p_i is the proportion of the ith species in a community (i.e. sample) and s is the number of species in the community (species richness).

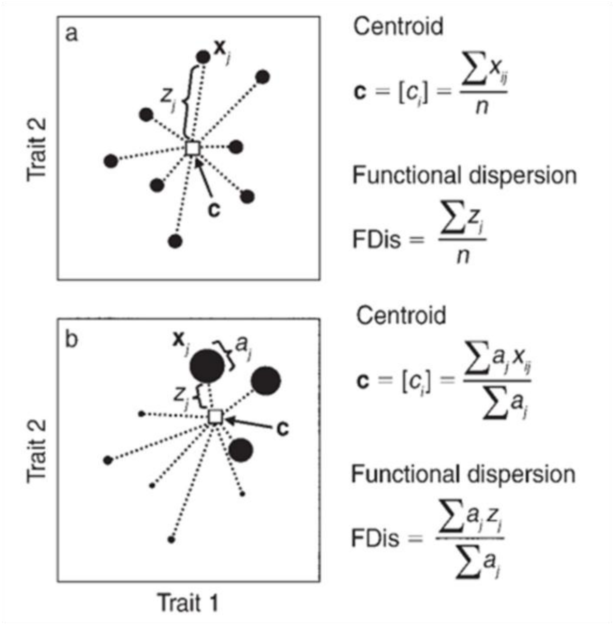


Fig. 4.2 An example showing how functional dispersion (FDis) is computed, based on figure 1 by Lalibertè and Legendre (2010). The *n* individual species in a two-dimensional trait space are represented by black circles whose sizes are proportional to their abundances. Vector $\mathbf{x}_j$ represents the position of species *j*, vector **c** is the centroid of the *n* species (white square), z_j is the distance of species *j* to centroid **c**, and a_j is the abundance of species *j*. In panel (a), all species have equal abundances (i.e., presence–absence data). In that case, $\mathbf{c} = [c_i]$, where c_i is the mean value of trait *i*, and FDis is the mean of distances *z* of individual species to **c**. In panel (b), species have different abundances. In that case, the position of **c** is weighted by the species relative abundances, such that it shifts toward the more abundant species. Individual distances *z* of species to **c** are weighted by their relative abundances to compute FDis.

Functional diversity was calculated by functional dispersion (FDis) index proposed by Lalibertè and Legendre (2010). FDis is the average distance in multidimensional trait space of individual species to the centroid of all species; it can account for species abundances by shifting the position of the centroid towards the more abundant species and weighting distances of individual species by their relative abundances (Fig. 4.2a). FDis is the multivariate analogue of the weighted mean absolute deviation (MAD) (Lalibertè and Legendre 2010). FDis can account for relative abundances by computing the weighted centroid of the $\mathbf{X} = [x_{ij}]$ (species × trait) matrix in the following way:

$$\mathbf{c} = [c_i] = \frac{\sum a_j x_{ij}}{\sum a_j}$$

where **c** is the weighted centroid in the *i*-dimensional space, a_j the abundance of species *j*, and x_{ij} the attribute of species *j* for trait *i* (Fig. 4.2b).

FDis, the weighted mean distance $\bar{z}$ to the weighted centroid **c**, is then computed as

$$\mathrm{FDis} = \frac{\sum a_j z_j}{\sum a_j}$$

where a_j is the abundance of species *j* and z_j is the distance of species *j* to the weighted centroid **c**.

Partitioning of diversity

Diversity has been traditionally defined as the variety and abundance of species in a defined unit of space (Magurran 2004). It is measured at various levels of resolution and decomposed into different spatial components highlighting the mechanisms that underlie ecological differentiation and species coexistence (Loreau 2000; Pavoine et al. 2004; de Bello et al. 2007). The total species diversity in a region (γ-diversity) can be partitioned into the within-community diversity (α-diversity) and the among-communities diversity (β-diversity; Whittaker 1975). This partitioning could be additive (e.g. $\gamma = \alpha + \beta$) or multiplicative ($\gamma = \alpha \times \beta$), depending on models and mathematical indices used (Lande 1996; Loreau 2000; Veech et al. 2002; Ricotta 2005; Jost 2007).

Alpha species diversity has been conventionally expressed as the number of coexisting species within a given community (i.e. species richness), or by composite indices that incorporate the proportion of each species (e.g. Simpson index; Magurran 2004 and references therein). Beta species diversity has been defined as the extent of turnover (or dissimilarity) among communities, i.e. how much diversity is added when pooling different communities together. Several methods for β species diversity measurements have been developed (Magurran 2004). One simple and intuitive formula is based on partitioning the different spatial components of species richness: $\beta = \gamma - \alpha$ (Lande 1996; Loreau 2000; Veech et al. 2002; Ricotta 2005), where β is defined as the difference between the total richness in a region (γ) and the average richness within all communities present in that area (α). The disadvantage of this approach is that the total regional richness (γ) is often estimated only using a subset of representative communities within the region (Magurran 2004). As a consequence, β and γ increase with the number of sampled units.

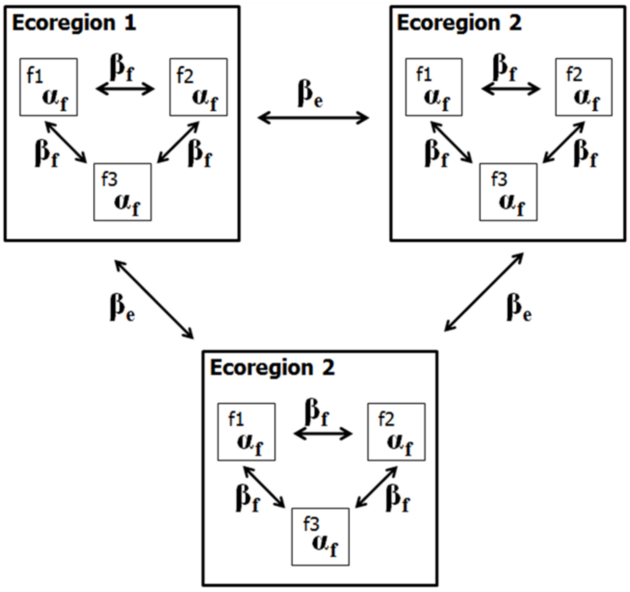


Fig. 4.3 Sampling design to evaluate Simpson diversity (D) and functional dispersion (FDis) at different scales. α and β correspond to D and FDis within and among samples at each scale (f, farm; e, ecoregion). Total regional richness (γ) is computed as $\gamma = \alpha_f + \beta_f + \beta_e$. Ecoregion: 1) 1000-1500 m a.s.l.; 2) 1500-2000 m a.s.l.; 3) 2000-2500 m a.s.l.

Additive partitioning was used to calculate alpha-diversity at the farm level (α_f) and beta-diversity at the farm (β_f) and regional (β_e) levels (Fig. 4.3). Simpson diversity and functional diversity were compared. Hierarchically nested sampling design was applied and included 9 vegetation plots within each of 8 summer farms belonging to three ecoregions (1) 1000-1500 m a.s.l.; 2) 1500-2000 m a.s.l.; 3) 2000-2500 m a.s.l.). At the local scale, additive diversity components was quantified from 216 vegetation plots (72 for each ecoregion, respectively) within 24 summer farms, and at the regional scale from 24 summer farms (8 farms for each ecoregion) within the study region. Total observed regional diversity (γ) was additively decomposed into its average components within (α_e) and among (β_e) farms, such that $\gamma = \alpha_e + \beta_e$. To investigate species diversity patterns at the local scale of the hierarchical sampling design, I decomposed the average within-grassland parcel component (α_e) into the within- (α_f) and among-vegetation plot (β_f) components, $\alpha_e = \alpha_f + \beta_f$. In the additive approach α_e is equivalent to γ-diversity at the local scale. Following Crist et al. (2003) α-diversity at the local scale and the β-diversities at both the local and regional scale sum to give total observed regional diversity: $\gamma = \alpha_f + \beta_f + \beta_e$. As α- and β-diversity components were expressed in the same units of species richness (Wagner et al. 2000) their relative contributions to γ can be directly compared.

Jost (2007) demonstrated for various species diversity indices, including the Simpson index of species diversity that β-diversity approaches zero as α-diversity becomes larger, even if the sampling units share no similar species. Overall, this means that the β-diversity will be low regardless of the actual species overlap and the change in diversity across sampling units (Jost 2007; de Bello et al. 2009). Therefore β-diversity estimated using Simpson's formulation could lead to meaningless ecological results (Ricotta & Szeidl 2009; Jost et al. 2010). This was shown to also be the case for indices commonly used in population genetics (Jost 2008). This limitation of the Simpson index in partitioning the spatial components of taxonomic diversity can be resolved by applying the correction proposed by Jost (2007) derived from equivalent numbers:

$$\alpha_{Eqv} = \frac{1}{1-\alpha};$$

$$\gamma_{Eqv} = \frac{1}{1-\gamma}$$

According to Jost (2007), the β-diversity in a region in terms of equivalent numbers can then be expressed as:

$$\beta_{Eqv} = \frac{\gamma_{Eqv}}{\alpha_{Eqv}}$$

The logic of the original correction of Jost (2006, 2007) is based on the concept of "equivalent communities". If α and β are to be independent of each other, so that one is not constrained in any way by the other, then this is the unique correct partitioning (Jost et al. 2010). This corresponds to calculating diversity for the case of *s* equally common species in a sampling unit (each species therefore with a proportion of $1/s$), with a resulting α-diversity expression that should equal the actual number of species in a community, i.e. species richness (Jost 2006). Although Jost's correction was originally proposed only for multiplicative partitioning of diversity (i.e. $\beta = \gamma / \alpha$), de Bello et al. (2010) showed that the correction could be equivalently applied to additive partitioning:

$$\beta_{Eqv} = \gamma_{Eqv} - \alpha_{Eqv}$$

With this extension of Jost's correction, β-diversity can be expressed as a proportion of the total regional diversity, which can be very useful when comparing different facets of diversity together (e.g. taxonomic, functional, and phylogenetic).

Statistical analysis

Species diversity of each plot was quantified by Simpson index of diversity (D), while functional diversity was estimated by functional dispersion index (FDis) on the basis of the 13 species traits. To compute FDis the 'FD' R-language package (http://cran.r-project.org/web/packages/FD) were used. 'FD' is a package to compute different multidimensional functional diversity (FD) indices. It implements a distance-based framework to measure FD that allows any number and type of functional traits (i.e. quantitative, semi-quantitative and qualitative), and can also consider species relative abundances. This package allows for missing trait values and the weighting of individual traits. 'FD' uses principal coordinates analysis (PCoA) to return PCoA axes, which are then used as 'traits' to compute FD (Lalibertè and Legendre 2010).

Pearson correlations between all the variables chosen in this study were examined to evaluate the degree of collinearity. Given that multicollinearity among explanatory variables can hamper the identification of the most causal variables (MacNally 2000), the number of explanatory variables was reduced using Pearson correlation coefficient >0.6; in case of highly correlated variables only one of them was used in the model (see Appendix C).

In order to determine the relative influence of the explanatory variables on Simpson diversity and functional diversity components (α-, β-, γ-diversity), multiple regression model [ordinary least squares (OLS) regression] was carried out. In all cases, quadratic terms were tested along with the linear terms to detect nonlinear relationships. In the multiple models, a backward selection of the variables was performed following the procedure suggested by Crawley (2007). Finally, the optimal models were validated by the analysis of residuals, to assess homogeneity and to verify normality (Zuur et al. 2009).

Hierarchical partitioning (HP) was also used to determine the relative importance of the variables most likely to affect variation in diversity components (Chevan and Sutherland 1991). HP allows the joint consideration of all the possible models in a multiple regression attempting to identify the most likely causal factors. This analysis splits the variation explained by each explanatory variable into a joint effect with the other explanatory variables and an independent effect not shared with any other variable. HP was conducted using the 'Hier.Part' package (version 1.0–3; Mac Nally and Walsh 2004) implemented in R version 2.10.1 (R Development Core Team 2009). As HP needs monotonic relationships between response variables and explanatory variables, I transformed the explanatory variables when appropriate to improve the linearity of the relationships. The independent effects were tested using a randomization routine (n= 200), which gives Z-scores for the generated distribution of randomized independent contributions and a level of statistical significance (P) based on this score. It was used a normal error distribution and R^2 as a measure of goodness-of-fit.

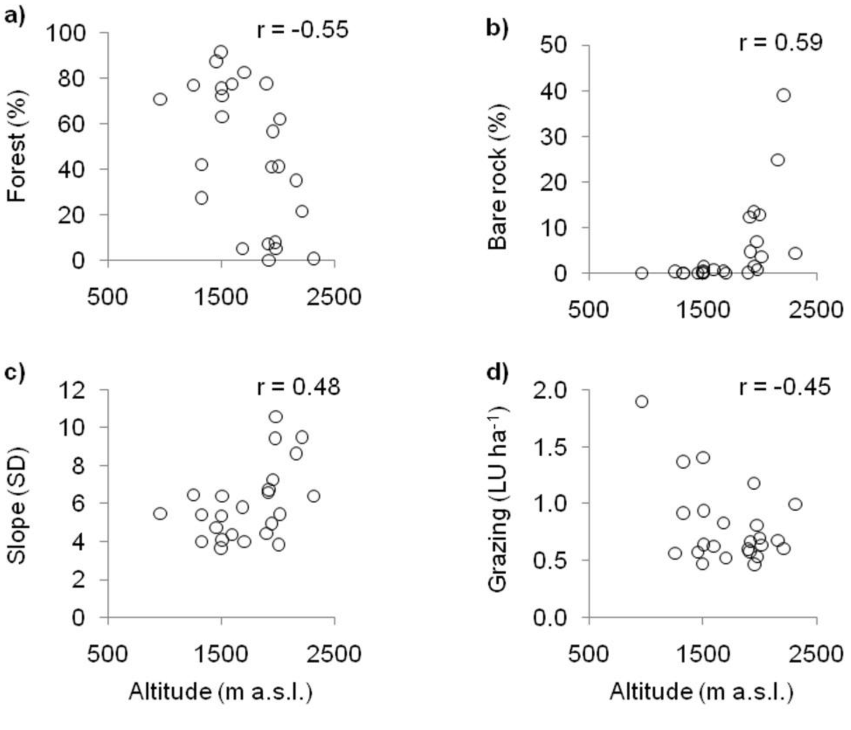


Fig. 4.4 Correlation between average farms altitude and landscape composition of each farms (**a**, proportion of forest; **b,** proportion of bare rock), topographic heterogeneity (**c**, standard deviation of slope) and grazing intensity (**d**, livestock unit ha^{-1}). All correlations are significant ($P < 0.01$).

RESULTS

The Simpson diversity components (α_s-, β_s-, γ_s-diversity) were positively correlated between them (Appendix C), while functional dispersion components (α_f-, β_f-, γ_f-diversity) showed a significant positively correlation between α_f- and γ_f-diversity and between β_f- and γ_f-diversity. Due to high collinearity between ALT and TEM, FOR and GRA, bedrock and landscape heterogeneity variables, I included only ALT, FOR, CAL and SLO_H in the analyses (see Appendix C).

Table 4.3 Multiple regression models [ordinary least squares (OLS)] for α-, β- and γ-Simpson diversity testing all the environmental predictors.

Variables	d.f.	OLS estimate	SE	*P*	OLS R^2
Simpson diversity					
α-diversity	**18**				**0.668**
Intercept		32.811	3.892	–	
ALT		-0.003	0.002	0.046	
CAL		0.035	0.008	<0.001	
FOR		0.110	0.048	0.032	
FOR^2		-0.002	0.001	0.010	
GRAZ		-3.496	1.278	0.014	
β-diversity	**18**				**0.760**
Intercept		10.067	9.8139	–	
ALT		0.014	0.0063	0.039	
CAL		0.101	0.0334	0.007	
ROCK		1.555	0.5554	0.012	
$ROCK^2$		2.822	0.9263	0.007	
SLO_H		-0.045	0.0145	0.006	
γ-diversity	**19**				**0.732**
Intercept		7.386	0.326	–	
CAL		0.007	0.002	0.003	
ROCK		0.127	0.029	<0.001	
$ROCK^2$		-0.003	0.001	0.001	
SLO_H		0.196	0.055	0.002	

Quadratic terms were also tested to detect nonlinear relationships. ALT, average altitude; CAL, area covered by calcareous bedrock; FOR, area covered by forest; ROCK, area covered by bare rock; SLO_H, slope heterogeneity; GRAZ, grazing intensity.

Considering the topography, landscape, bedrock types and management of 24 farms, the correlation between altitude and the former variables was analyzed (Fig. 4.4). At landscape level, a negative correlation between altitude and forest proportion (*r* = -055, *P*<0.01) and positive correlation between altitude and bare rock proportion (*r* = 059, *P*<0.01) were found. In view of morphology of summer farms, a positive correlation occurred between altitude and slope heterogeneity (*r* = 048, *P*<0.05). Considering management of each summer farms, a negative correlation occurred between altitude and grazing intensity (*r* = -045, *P*<0.05).

The results of the multiple regression models testing environmental predictors on Simpson diversity components (α_s-, β_s-, γ_s-diversity) were reported in Table 4.3. The model for Simpson α-diversity explained less variation (67%) that for γ-diversity (73%) and β-diversity (76%) models. For α-diversity, the model retained ALT, CAL, FOR and GRAZ. For β-diversity, the model included ALT, CAL, ROCK and SLO_H. Finally, for γ-diversity the model included CAL, ROCK and SLO_H.

The functional dispersion components (α_f-, β_f-, γ_f-diversity) models were reported in Table 4.4. Again, the model for α-diversity explained less variation (19%) that for γ-diversity (20%) and β-diversity (24%) models, as seed above. For α-diversity, the model retained only GRAZ. For β-diversity and γ diversity, the models included only ALT. Respect Simpson diversity components models, functional dispersion models explained less variation.

Table 4.4 Multiple regression models [ordinary least squares (OLS)] for α-, β- and γ-functional dispersion testing all the environmental predictors.

Variables	d.f.	OLS estimate	SE	*P*	OLS R^2
Functional dispersion					
α-diversity	**22**				**0.193**
Intercept		1.124	0.004	–	
GRAZ		-0.011	0.004	0.0182	
β-diversity	**22**				**0.236**
Intercept		-0.002	0.003	–	
ALT		0.000	0.000	0.009	
γ-diversity	**22**				**0.201**
Intercept		1.099	0.009	–	
ALT		0.000014	0.000005	0.016	

Quadratic terms were also tested to detect nonlinear relationships. ALT, average altitude; GRAZ, grazing intensity.

The results of hierarchical partitioning (HP) analysis highlighted that CAL was the most important variable explaining large fractions of variation for Simpson α-diversity (*c*. 65%), while the other variables had a small independent effect (<15%) (Fig. 4.5a). For Simpson β-diversity, ALT (*c.* 31%) and SLO_H (*c.* 22%) showed the largest independent effects, followed by FOR and CAL (*c.* 17%) (Fig. 4.5b). For Simpson γ-diversity, the relative importance of CAL, ALT and SLO_H was higher (>20%) compared to that of other variables (Fig. 4.5c).

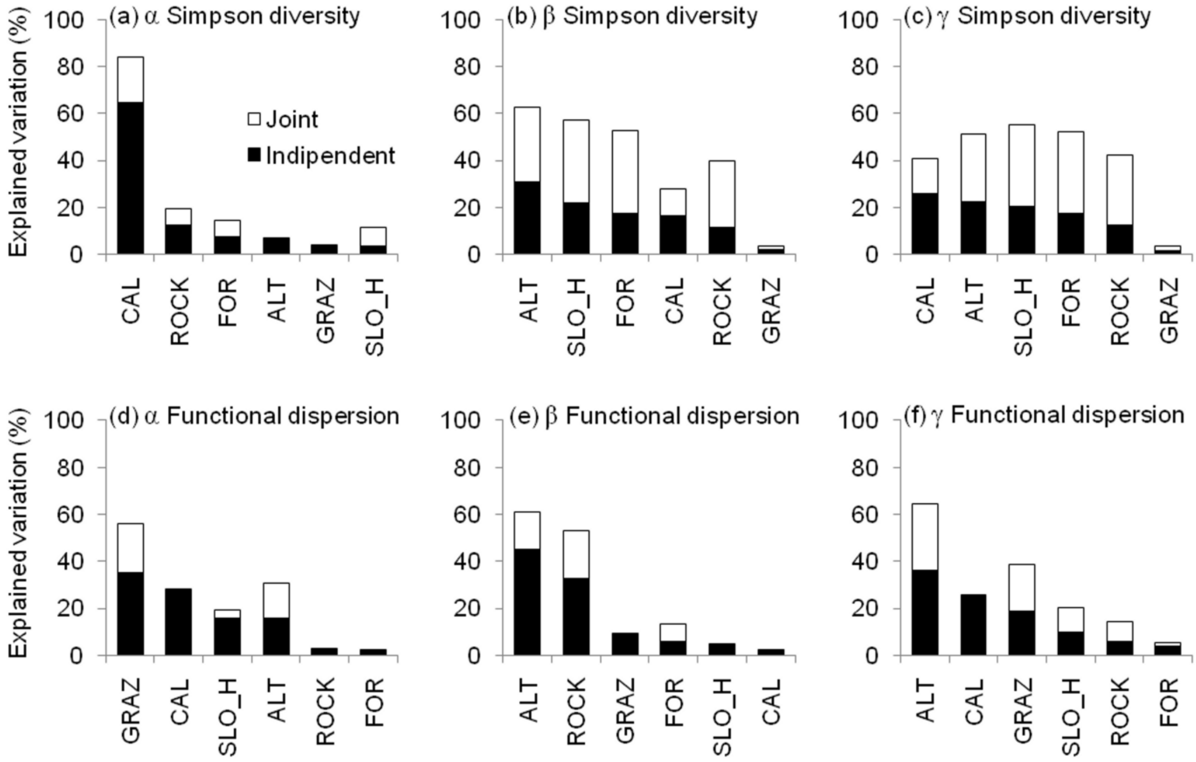


Fig. 4.5 The independent and joint contributions (given as the percentage of the total explained variation) of each explanatory variable for the Simpson diversity components (a) α-diversity, (b) β-diversity, (c) γ-diversity, and for the functional diversity components (d) α-diversity, (e) β-diversity, (f) γ-diversity estimated from hierarchical partitioning (HP). The models are shown, ranked in decreasing independent effect. ALT, average altitude; CAL, area covered by calcareous bedrock; FOR, area covered by forest; ROCK, area covered by bare rock; SLO_H, slope heterogeneity; GRAZ, grazing intensity.

In all the analysis GRAZ showed very small independent effects (<5%). Considering, functional dispersion the results of HP analysis highlighted that GRAZ (*c.* 35%) and CAL (*c.* 28%) were the most important variable explaining large fractions of variations for α functional dispersion, followed by SLO_H and ALT (*c.* 15%) (Fig. 4.5d). For β functional dispersion, ALT (*c.* 45%) and ROCK (*c.* 32%) showed the largest independent effects, while the other variables had a small independent effect (<10%) (Fig. 4.5e). Finally, for γ functional dispersion ALT (*c.* 36%), CAL, (*c.* 26%) and GRAZ (*c.*

19%) showed the largest independent effects (Fig 4.5f). Respect Simpson diversity components, in functional dispersion HP analysis GRAZ explained higher variation (10-35%). Finally, the results showed a much more marked turnover in species (as Simpson diversity) than in functional trait diversity among communities (functional dispersion) (Fig. 4.6).

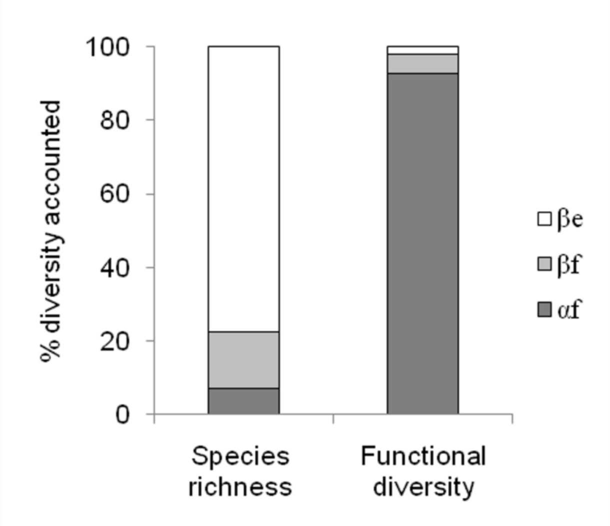


Fig.4.6 Contrasting partitioning of species richness (based on Simpson index of diversity) versus functional diversity (based on the functional dispersion) into α_f (‘‘within-summer farms’’) β_f (‘‘among-summer farms’’) and β_e (“among-ecoregions”) components over all locations considered.

DISCUSSION

Our observational study in managed grasslands reveals support that additive diversity partitioning provides understanding of local-regional patterns of species diversity and spatial scale dependence of diversity components (Gering & Crist, 2002; Gering et al., 2003; Loreau, 2000). In the present study, the relative contributions of β_e-Simpson diversity (“among ecoregions”) component to total observed regional diversity (γ) was remarkably consistent, while for functional diversity was higher the relative contribution α_f-functional dispersion (“between farms”), indicating high importance of scale-specific diversity components (Fig. 4.6). Analyses of plant species diversity patterns in grasslands demonstrated that the relative contributions of additive diversity components to total observed regional species richness changed as a function of spatial scale.

As suggested by Loreau (2000), β-diversity at each scale can be seen as the result of environmental heterogeneity in space and time, in combination with niche differences among species. This author concluded that movements between spatial units like dispersal or migration can act as a homogenising force, which can increase α-diversity at the expense of β-diversity. However, spatial analyses demonstrated that pasture plant communities in our study region were not spatially autocorrelated, indicating that spatial heterogeneity in species richness among grassland parcels (β) was not lowered due to a homogenising effect.

The modest turnover of FD among communities contrasts with the high turnover of species among habitats (Whittaker 1975; Fig. 4.6). This study , as those in Pavoine and Dolédec (2005), de Bello et al. (2009) show a much more marked turnover in species (as β species richness) than in functional trait diversity among communities (β FD). This result implies that a high replacement in species composition (taxonomical turnover) might result in a rather stable functional assemblage for certain traits (low functional turnover; e.g. Fukami et al. 2005), suggesting the existence of ecological redundancy among communities (Petchey et al. 2007).

In a recent investigation in the Pyrenees (Mottet et al. 2006) and in the Swiss Alps (Kampmann et al. 2008) identified slope and elevation as driving forces in decision making for management type, and good accessibility of parcels as a prerequisite for maintaining pastoral management, and preventing abandonment. In this study, was observed a relation between altitude gradient of summer farms and environmetal, landscape and management variables. Farms located in higher sites showed lower grazing intensity, probably due to influence of topography and landscape hetereogenity on management practices (Fig. 4.4). Kampmann et al. (2008) and Rudmann-Maurer et al. (2008) found in the Swiss Alps which landuse types were not distributed randomly in the landscape. These analyses of differences in abiotic variables among landuse types confirmed the assumption that farmers in the Swiss Alps try to optimize their workload. Abandoned parcels were situated at higher altitudes or had steeper slopes, which implies a low accessibility, while only parcels at lower altitudes and with lower slopes were fertilized.

At the local scale, was found that α-Simpson diversity (“between farms”) was mainly explained by bedrock type. Farms located in calcareous substrates showed higher species richness. Cover of calcareous bedrock was further key factor increasing species richness (see also Wohlgemuth, 1998; Moser et al., 2005; Marini et al., 2008b). This well-known broad pattern for the native European flora has been suggested to be the result of processes such as speciation and extinction dynamics related to the prevalence of basic substrates in Europe or other potential factors confounded with calcareous bedrock (Wohlgemuth and Gigon, 2003). Considering α-functional diversity HP analysis highlighted that grazing intensity was the most important variable. Field management practices implied a lower functional dispersion in sites intensively grazed, while higher dispersion in extensive areas. As seen previosusly, β-diversity has been defined as the extent of turnover (or dissimilarity) among communities. The analysis showed that β-Simpson diversity and β-functional diversity was mainly explained by altitude. The turnover of species and related dispersion of plant traits among communities was linked to elevation gradient of farms, but also to covariation with grazing intensity and landscape hetereogeneity (altitude, landscape composition, topography hetereogeneity and grazing intensity were interrelated between them, Fig. 4.4).

There is evidence that grazing animals (direct and indirect effects was found in the study area) can alter grassland vegetation by creating spatial heterogeneity in the nutrient distribution and sward structure through selective grazing, trampling, deposition of excreta (Adler et al., 2001; Rook et al., 2004; Vickery et al., 2001), and by acting as dispersal agents (Poschlod et al., 2005). At a low-to-moderate stocking density, these small-scale disturbances have been suggested to promote plant species richness by providing a large number of different microsites, thereby enabling coexistence of a large variety of plant species (Collins et al. 1998). In this study, stocking density averaged less than one livestock-unit per hectare and year, and there is evidence, that high grassland diversity is generally associated with low-input livestock systems (Duru and Hubert, 2003). In view of the results, patchy disturbances due to low-input livestock grazing in pastures may decrease the role of competition at the local scale and facilitate regional enrichment of grassland plant communities by enabling species establishment from the regional species pool. Hence, processes such as dispersal and establishment

(Collins et al. 2002; Poschlod et al. 2005) might be of greater importance for β-diversity of all plant species within extensive grazed pastures at the local scale.

In this study, additive diversity partitioning facilitated a quantification and comparison of the relative contributions of α- and β-diversity components to total regional diversity along an elevation gradient. Based on the results, I conclude that the observed patterns of plant species diversity appeared to be influenced by processes at multiple spatial scales. This approach has limitations, since other factors not considered in this study dispersal limitation and sampling efficiency may also have a great role in influencing patterns of β-diversity (Crist & Veech, 2006; Gabriel et al., 2006). However, the results indicate that the maintenance of a large variety of grassland utilisation systems along with heterogeneous abiotic environmental conditions appears to be a promising tool for the conservation of species richness and functional diversity due to enhanced β-diversity among pastures parcels.

CHAPTER 5

SYNTHESIS:
CLASSIFICATION AND BIODIVERSITY PATTERNS IN PASTURES OF PROVINCE OF TRENTO

The elaboration of more than 1500 vegetation relevees, analyzed by cluster analysis, made it possible to classify the most common types of pasture in the Province of Trento. It has allowed to identify four main groups of pastures (a, mesic and degraded pastures; b, pastures on calcareous bedrocks; c, pastures on siliceous bedrocks; d, shrubbed and reforested pastures) characterized by soil fertility, the type of bedrock (calcareous or siliceous) and grazing management (e.g. extensive, degraded, abandoned pastures). The elaboration of each division confirmed as multivariate analysys (classification and ordination) has often kept together the vegetation formations from the same geographic district and representative of close vegetation types. To sum up, geography has played a very important effect on species composition; conditioning largely attributable to environmental factors specific to each location (climate, substrate, soil and altitude). But it seems likely that other factors, as phytogeography, played a main role. These results suggest a good correspondence between traditional expert-based associations recognized in the Italian Alps and an overall floristic variation within this study area (**CHAPTER 2**)

The patterns of species richness and species composition found in alpine pastures, result from the interaction of different environmental and management factors operating at different spatial scales. The results indicate that at small scales (within farms) species richness is mainly determined by slope, while specie composition is controlled by distance from the farm centre as well as slope. At large scale (between farms), was observed a key role of grazing intensity and bedrock types on species diversity patterns. The results highlighted that the identification of appropriate stocking rates appears to be the most promising approach to conserve the high biodiversity of alpine pastures, as both intensification and abandonment changed species composition and reduced plant species diversity. (**CHAPTER 3**)

In this study, additive diversity partitioning facilitated a quantification and comparison of the relative contributions of α- and β-diversity components to total regional diversity along an elevation gradient. Based on the results, I conclude that the observed patterns of plant species diversity appeared to be influenced by processes at multiple spatial scales. The results indicate that the maintenance of a large variety of grassland utilisation systems along with heterogeneous abiotic environmental conditions appears to be a promising tool for the conservation of species richness and functional diversity due to enhanced β-diversity among pastures parcels. Moreover, this study showed a much more marked turnover in species (as β species richness) than in functional trait diversity among communities (β functional dispersion). This result implies that a high replacement in species composition (taxonomical turnover) might result in a rather stable functional assemblage for certain traits, suggesting the existence of ecological redundancy among communities. (**CHAPTER 4**)

REFERENCES

Ackerly, D.D. & Cornwell, W.K. (2007) A trait-based approach to community assembly: partitioning of species trait values into within- and among-community components. *Ecology Letters*, 10, 135–145.

Adler, P.B., Raff, D.A. & Lauenroth, W.K. (2001) The effect of grazing on the spatial heterogeneity of vegetation. *Oecologia*, 128, 465–479.

Äschimann, D., Lauber, K., Moser, D.M. & Theurillat, J.P. (2004) *Flora Alpina* . Zanichelli, Bologna

Badía, D., Martí, C., Sánchez, J.R., Fillat, F., Aguirre, J. & Gómez, D. (2008) Influence of livestock soil eutrophication on floral composition in the pyrenees mountains. *Journal of Mountain Science*, 5, 63-72.

Bakker, J.P. (1989) *Nature management by grazing and cutting*. Kluwer, Dordrecht.

Bakker, J.P., Elzinga, J.A. & de Vries, Y. (2002. Effects of long-term cutting in a grassland system: Perspectives for restoration of plant communities on nutrient poor soils. *Applied Vegetation Science*, 5, 107–120.

Bennie, J., Hill, M.O., Baxter, R. & Huntley, B. (2006). Influence of slope and aspect on long-term vegetation change in British chalk grasslands. *Journal of Ecology*, 94, 355-368.

Bertiller, M.B., Mazzarino, M.J., Carrera, A.L., Diehl, P., Satti, P., Gobbi, M. & Sain, C.L. (2006) Leaf strategies and soil N across a regional humidity gradient in Patagonia. *Oecologia*, 148, 612–624.

Bezzi, A., Ropelato, A. (1974-75) Il pascolo dell'Alpe di Pampeago; Studio fitosociologico applicato al calcolo del carico di bestiame. *Annali dell'ISAFA* vol. 4 (1974-75), Trento.

Bezzi, A., Orlandi, D. (1978-79) Proposta metodologica per la pianificazione di pascoli alpini (Val Rendena, Trento). *Annali dell'ISAFA* vol. 7 (1978-79), Trento.

Bezzi, A., Feoli, E., Orlandi, D. (1980-82) Sintesi sulla vegetazione degli alpeggi della Val Rendena (Trento). *Annali dell'ISAFA* vol. 8 (1980-82), Trento.

Bezzi, A. (1983-84) La vegetazione dei pascoli di Malga Tassulla (Tassullo, Trento): metodi di elaborazione dei rilievi fitosociologici a scopi agro-zootecnici. *Annali dell'ISAFA* vol. 9 (1983-84), Trento.

Bezzi, A., Orlandi, D., Clementel, F. (1993) La tipologia dei pascoli alpini: metodi di rilevamento e di elaborazione dei dati adottati dalla sezione Alpicoltura dell'I.S.A.F.A. *Comunicazioni di Ricerca dell'ISAFA* 93/1, Trento.

Blanchet, F.G., Legendre, P. & Borcard, D. (2008) Forward selection of explanatory variables. *Ecology*, 89, 2623-2632.

Bosellini, A., Castellarin, A., Dal Piaz, G.V. & Nardin, M. (1999) *Carta litologica e dei lineamenti strutturali del Trentino (1: 200 000)*. Servizio Geologico della Provincia Autonoma di Trento, Trento.

Braun-Blanquet, J., Jenny, J., (1926) Vegetationsentwicklung und Bodenbildung in der alpinen Stufe der Zentralalpen. *Denkschr. Schweiz. Naturforsch. Ges*., 63, 183–349.

Cavallero, A., Aceto, P., Gorlier, A., Lombardi, G., Lonati, M., Martinasso, B. & Tagliatori, C. (2007) I tipi pastorali delle Alpi piemontesi. Alberto Perdisa Editore, Bologna.

Chesson, P., Gebauer, R.L.E., Schwinning, S., Huntly, N., Wiegand, K., Ernest, M.S.K., Sher, A., Novoplansky, A. & Weltzin, J.F. (2004) Resource pulses, species interactions, and diversity maintenance in arid and semi-arid environments. *Oecologia*, 141, 236–253

Chevan, A. & Sutherland, M. (1991) Hierarchical partitioning. *The American Statistician*, 45, 90–96.

Collins, S.L., Knapp, A.K., Briggs, J.M., Blair, J.M. & Steinauer, E.M. (1998). Modulation of diversity by grazing and mowing in native tallgrass prairie. *Science*, 280, 745–747.

Collins, S.L., Glenn, S.M. & Briggs, J.M. (2002) Effects of local and regional processes on plant species richness in tallgrass prairie. *Oikos*, 99, 571–579.

Connell, J.H. (1978) Diversity of tropical rainforests and coral reefs. *Science*, 199, 1304–1310.

Cornwell, W.K., Schwilk, D.W. & Ackerly, D.D. (2006) A trait-based test for habitat filtering: convex hull volume. *Ecology*, 87, 1465–1471.

Crawley, M.J. (2007) *The R book*. John Wiley and Sons, Ltd, Chichester.

Critchley, C.N.R., Chambers, B.J., Fowbert, J.A., Sanderson, R.A., Bhogal, A. & Rose, S.C. (2002) Association between lowland grassland plant communities and soil properties. *Biological Conservation*, 105, 199–215.

Crist, T. O., Veech, J. A., Gering, J. C., & Summerville, K. S. (2003) Partitioning species diversity across landscapes and regions: a hierarchical analysis of alpha, beta, and gamma diversity. *American Naturalist*, 162, 734–743.

Crist, T.O. & Veech, J.A. (2006) Additive partitioning of rarefaction curves and species–area relationships: unifying alpha-, beta- and gamma-diversity with sample size and habitat area. *Ecology Letters*, 9, 923–932.

Currie, D.J. (1991) Energy and large-scale patterns of animal and plant-species richness. *The American Naturalist*, 137, 27–49.

de Bello, F., Lepš, J. & Sebastià, M.T. (2006) Variations in species and functional plant diversity along climatic and grazing gradients. *Ecography*, 29, 801–810.

de Bello, F., Lepš, J. & Sebastià, M.T. (2007) Grazing effects on the species–area relationship: variation along a climatic gradient in NE Spain. *Journal of Vegetation Science*, 18, 25–34.

de Bello, F., Thuiller, W., Lepš, J., Choler, P., Clement, J.C., Macek, P., Sebastiá, M.T. & Lavorel, S. (2009) Partitioning of functional diversity reveals the scale and extent of trait convergence and divergence. *Journal of Vegetation Science*, 20, 475–486.

de Bello, F., Lavergne, S., Meynard, C.N., Lepš, J., Thuiller, W. (2010) FORUM The partitioning of diversity: showing Theseus a way out of the labyrinth. In press

Díaz, S., Cabido, M. & Casanoves, F. (1998) Plant functional traits and environmental filters at a regional scale. *Journal of Vegetation Science*, 9, 113–122.

Díaz, S. & Cabido, M. (2001) Vive la difference: plant functional diversity matters to ecosystem processes. *Trends in Ecology & Evolution*, 16, 646–655.

Díaz, S., Lavorel, S., de Bello, F., Quetier, F., Grigulis, K. & Robson, T.M. (2007) Incorporating plant functional diversity effects in ecosystem service assessments. *Proceedings of the National Academy of Sciences of the United States of America*, 104, 20684–20689.

Dullinger, S., Dirnböck, T., Greimler, J. & Grabherr, G. (2003) A resampling approach for evaluating effects of pasture abandonment on subalpine plant species diversity. *Journal of Vegetation Science*, 14, 243–252.

Duru, M. & Hubert, B. (2003) Management of grazing systems: From decision and biophysical models to principles for action. *Agronomie*, 23, 689–703.

Ellenberg, H., Weber, H.E., Düll, R., Wirth, V., Werner, W. & Paulisen, D. (1991) Zeigerwerte von Pflanzen in Mitteleuropa. *Scripta Geobotanica*, 18, 1–248.

Ellenberg, H. (1996) *Vegetation Mitteleuropas mit den Alpen*, 5th edn. Verlag Eugen Ulmer, Stuttgart.

Ewald, J. (2003) The calcareous riddle: why are there so many calciphilous species in the central European flora? Folia Geobotanica, 38, 357–366.

Fischer, M. & Wipf, S. (2002) Effect of low-intensity grazing on the species-rich vegetation of traditionally mown subalpine meadow. *Biological Conservation,* 104, 1-11.

Fukami, T., Bezemer, T.M., Mortimer, S.R. & van der Putten, W.H. (2005) Species divergence and trait convergence in experimental plant community assembly. *Ecology Letters*, 8, 1283–1290.

Gabriel, D., Roschewitz, I., Tscharntke, T., & Thies, C. (2006) Beta diversity at different spatial scales: Plant communities in organic and conventional agriculture. *Ecological Applications*, 16, 2011–2021.

Garnier, E., Cortez, J., Billes, G., Navas, M.L., Roumet, C., Debussche, M., Laurent, G., Blanchard, A., Aubry, D., Bellmann, A., Neill, C. & Toussaint, J.P. (2004) Plant functional markers capture ecosystem properties during secondary succession. *Ecology,* 85, 2630–2637.

Gering, J. C. & Crist, T. O. (2002) The alpha-beta-regional relationship: Providing new insights into local-regional patterns of species richness and scale dependence of diversity components. *Ecology Letters*, 5, 433–444.

Gering, J. C., Crist, T. O., & Veech, J. A. (2003) Additive partitioning of species diversity across multiple spatial scales: Implications for regional conservation of biodiversity. *Conservation Biology*, 17, 488–499.

Gerola, F.M. & Gerola, D.U., (1955a) Ricerche sui pascoli delle Alpi Centro-Orientali. 1. Flora e vegetazione (Lessini – Baldo – Stivo – Pasubio). *Memorie del Museo di Storia Naturale della Venezia Tridentina*, Vol. X, Fasc. 1, Trento.

Gerola, F.M. & Gerola, D.U., (1955b) Ricerche sui pascoli delle Alpi Centro-Orientali. 1. Flora e vegetazione (Asiago – Vezzena – Vigolana). *Memorie del Museo di Storia Naturale della Venezia Tridentina*, Vol. X, Fasc. 2, Trento.

Gerola, F.M. & Gerola, D.U., (1957) Ricerche sui pascoli delle Alpi Centro-Orientali. 1. Flora e vegetazione (Altopiano di Pinè, Bacino del Brenta, Bacino dell'Avisio – Alpe di Siusi). *Memorie del Museo di Storia Naturale della Venezia Tridentina*, Vol. XI: 74-446, Trento.

Grime, J.P. (1973) Competitive exclusion in herbaceous vegetation. *Nature*, 242, 244–247.

Grime, J.P. (2001) *Plant strategies, vegetation processes, and ecosystems properties*, 2nd edn. John Wiley & Sons, Chichester.

Grime, J.P. (2006) Trait convergence and trait divergence in herbaceous plant communities: mechanisms and consequences. *Journal of Vegetation Science*, 17, 255–260.

Güsewell, S., Jewell, P.L. & Edwards, P.J. (2005) Effects of heterogeneous habitat use by cattle on nutrient availability and litter decomposition in soils of an Alpine pasture. *Plant and Soil*, 268, 135–149.

Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setala, H., Symstad, A.J., Vandermeer, J. & Wardle, D.A. (2005) Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs*, 75, 3–35.

Huston, M. A. (1999) Local processes and regional patterns: Appropriate scales for understanding variation in the diversity of plants and animals. *Oikos*, 86, 393–401.

Jewell, P.L., Güsewell, S., Berry, N.R., Käuferle, D., Kreuzer, M. & Edwards, P.J. (2005) Vegetation patterns maintained by cattle grazing on a degraded mountain pasture. *Botanica Helvetica*, 115, 109–124.

Jost, L. (2006) Entropy and diversity. *Oikos*, 113, 363–375.

Jost, L. (2007) Partitioning diversity into independent alpha and beta components. *Ecology*, 88, 2427-2439.

Jost, L. (2008) G(ST) and its relatives do not measure differentiation. *Molecular Ecology*, 17, 4015–4026.

Jost, L., DeVries, P., Walla, T., Greeney, H., Chao, A. & Ricotta, C. (2010) Partitioning diversity for conservation analyses. *Diversity and Distribution*, 16, 65–76.

Kampmann, D., Herzog, F., Jeanneret, P., Konold, W., Peter, M., Walter, T., Wildi, O. & Lüscher, A. (2008) Mountain grassland biodiversity: impact of site conditions versus management type. *Journal of Nature Conservation*, 16, 12–25.

Klaudisová, M., Hejcman, M. & Pavlů, V. (2009) Long-term residual effect of short-term fertilizer application on Ca, N and P concentrations in grasses *Nardus stricta* L. and *Avenella flexuosa* L. *Nutrient Cycling in Agroecosystems*, 85, 187-193.

Kleijn, D. & Müller-Schärer, H. (2006) The relation between unpalatable species, nutrients and plant species richness in Swiss montane pastures. *Biodiversity and Conservation*, 15, 3971 -3982.

Kleyer, M., Bekker, R.M., Knevel, I.C., Bakker, J.P., Thompson, K., Sonnenschein, M., Poschlod, P., van Groenendael, J.M., Klimeš, L., Klimešová, J., Klotz, S., Rusch, G.M., Hermy, M., Adriaens, D., Boedeltje, G., Bossuyt, B., Dannemann, A., Endels, P., Götzenberger, L., Hodgson, J.G., Jackel, A.K., Kühn, I., Kunzmann, D., Ozinga, W.A., Römermann, C., Stadler, M., Schlegelmilch, J., Steendam, H.J., Tackenberg, O., Wilmann, B., Cornelissen, J.H.C., Eriksson, O., Garnier, E., & Peco B. (2008) The LEDA traitbase: a database of life-history traits of Northwest European flora. *Journal of Ecology*, 96, 1266–1274.

Klimek, S., Kemmermann, A.R.G., Hofmann, M. & Isselstein, J. (2007) Plant species richness and composition in managed grasslands: the relative importance of field management and environmental factors. *Biological Conservation*, 134, 559-570.

Knapp, R. (1971) *Einführung in die Planzensoziologie*. Ulmer Verlag, Stuttgart.

Klotz, S., Kühn, I., & Durka, W. (2002) *BIOFLOR–Eine Datenbank mit biologisch-ökologischen Merkmalen zur Flora von Deutschland*. Schriftenreihe für Vegetationskunde 38, Bonn.

Kruess, J. & Tscharntke, T. (2002) Grazing intensity and the diversity of grasshoppers, butterflies, and trapnesting bees and wasps. *Conservation Biology*, 16, 1570–1580.

Lalibertè, E. & Legendre, P. (2010) A distance-based framework for measuring functional diversity from multiple traits. *Ecology*, 91, 299-305.

Lande, R. (1996) Statistics and partitioning of species diversity, and similarity among multiple communities. *Oikos*, 76, 5–13.

Legendre, P. & Gallagher, E.D. (2001) Ecologically meaningful transformations for ordination of species data. *Oecologia*, 129, 271-280.

Legendre, P., Borcard, D. & Peres-Neto, P.R. (2005) Analyzing beta diversity: partitioning the spatial variation of community composition data. *Ecological Monographs*, 75, 435–450.

Liu, K., Eastwood, R.J., Flynn, S., Turner, R.M. & Stuppy, W.H. (2008) *Seed Information Database* (release 7.1, May 2008). Available at: http://www.kew.org/data/sid

Loreau, M. (2000) Are communities saturated? On the relationship between alpha, beta and gamma diversity. *Ecology Letters*, 3, 73–76.

MacArthur, R. & Levins, R. (1967) The limiting similarity, convergence, and divergence of coexisting species. *The American Naturalist*, 101, 377–385.

MacDonald, D., Crabtree, J.R., Wiesenger, T.D., Stamou, N., Fleury, P., Gutierrez Lazpita, J. & Gibon, A. (2000) Agricultural abandonment in mountain areas of Europe: environmental consequences and policy response. *Journal of Environmental Management*, 59, 47–69.

MacNally, R. (2000) Regression and model-building in conservation biology, biogeography, and ecology: the distinction between – and reconciliation of – 'predictive' and 'explanatory' models. *Biodiversity and Conservation*, 9, 655–671.

Mac Nally, R. & Walsh, C. (2004) Hierarchical partitioning public-domain software. *Biodiversity and Conservation*, 13, 659–660.

Magurran, A.E. (2004) *Measuring biological diversity*. Blackwell, Oxford.

Marini, L., Scotton, M., Klimek, S., Isselstein, J. & Pecile, A. (2007) Effects of local factors on plant species richness and composition of Alpine meadows. *Agricultural, Ecosystems & Environment*, 119, 281-288.

Marini, L., Scotton, M., Klimek, S., Isselstein, J. & Pecile, A. (2008a) Patterns of plant species richness in Alpine hay meadows: Local vs. landscape controls. *Basic and Applied Ecology*, 9, 365-372.

Marini, L., Prosser, F., Klimek, S. & Marrs, R.H. (2008b) Water–energy, land-cover, and heterogeneity drivers of the distribution of plant species richness in a mountain region of the European Alps. *Journal of Biogeography*, 35, 1826–1839.

Marini, L., Fontana, P., Klimek, S., Battisti, A. & Gaston, K.J. (2009) Impact of farm size and topography on plant and insect diversity of managed grasslands in the Alps. *Biological Conservation*, 142, 394-403.

Mason, N.W.H., Mouillot, D., Lee, W.G. & Wilson, J.B. (2005) Functional richness, functional evenness and functional divergence: the primary components of functional diversity. *Oikos*, 111, 112–118.

Mason, N.W.H., Lanoiselee, C., Mouillot, D., Irz, P. & Argillier, C. (2007) Functional characters combined with null models reveal inconsistency in mechanisms of species turnover in lacustrine fish communities. *Oecologia*, 153, 451–452.

Moser, D., Dullinger, S., Englisch, T., Niklfeld, H., Plutzar, C., Sauberer, N, Zechmeister, H.G. & Grabherr, G. (2005) Environmental determinants of vascular plant species richness in the Austrian Alps. *Journal of Biogeography*, 32, 1117–1127.

Mottet, M., Ladet, S., Coqué, N. & Gibon, A. (2006) Agricultural land-use change an its drivers in mountain landscapes: a case study in the Pyrenees. *Agricultural, Ecosystems & Environment*, 114, 269–310.

Mouillot, D., Dumay, O. & Tomasini, J.A. (2007) Limiting similarity, niche filtering and functional diversity in coastal lagoon fish communities. *Estuarine Coastal and Shelf Science*, 71, 443–456.

Mucina, L., Grabherr, G., Ellmauer, Th. & Wallnöfer, S. (1993a) *Die Pflanzengesellschaft Österreichs: Teil I: Anthropogene Vegetation*. Gustav Fischer Verlag, Jena.

Mucina, L., Grabherr, G., Ellmauer, Th. & Wallnöfer, S. (1993b) *Die Pflanzengesellschaft Österreichs: Teil II: Natürliche waldfreie Vegetation*. Gustav Fischer Verlag, Jena.

Muller, P., Gusewell, S. & Edwards, P.J. (2003) Impacts of soil conditions and agricultural land use on plant species richness of Alpine pastures in the south of Glarus**.** *Botanica Helvetica*, 113, 15-36.

Niedrist, G., Tasser, E., Lüth, C., Dalla Via, J. & Tappeiner, U. (2009) Plant diversity declines with recent land use changes in European Alps. *Plant Ecology*, 202, 195-210.

Norris, K. (2008) Agriculture and biodiversity conservation: opportunity knocks. *Conservation Letters*, 1, 2-11.

Odasso M (2002) *I tipi forestali del Trentino*. Report 25. Centro di Ecologia Alpina, Trento.

Olff, H. & Ritchie, M.E. (1998) Effects of herbivores on grassland plant diversity. *Trends in Ecology & Evolution*, 13, 261-265.

Orlandi, D. (1983-84) I pascoli dell'alta val di Bresimo (Val di Non, Trento). Vegetazione, produttività e proposte di miglioramento. *Annali dell'ISAFA* vol. 9 (1983-84), Trento.

Orlandi, D. & Clementel, F. (1989) Valutazione della produttività di alcuni pascoli alpini sulla base degli indici ecologici di Landolt. *Annali dell'ISAFA* vol. 12 (1989), Trento.

Orlandi, D., Clementel, F. & Bezzi, A. (1997) Effetti di diversi tipi di fertilizzanti sulla composizione floristica e sul valore nutritivo di un nardeto. *Comunicazioni di Ricerca dell'ISAFA* 96/2, Trento.

Orlandi, D., Clementel, F., Scartezzini, F. & Floris, A., (2000) Caratterizzazione e cartografia dei pascoli di una malga alpina (Malga Juribello – Trento). *Comunicazioni di ricerca dell'ISAFA* 2000/1, Trento

Pärtel, M., Zobel, M., Zobel, K. & van der Maarel, E. (1996) The species pool and its relation to species richness: Evidence from Estonian plant communities. *Oikos*, 75,111–117.

Pavoine, S., Ollier, S. & Pontier, D. (2004) Measuring, diversity from dissimilarities with Rao's quadratic entropy: are any dissimilarities suitable? *Theoretical Population Biology*, 67, 231–239.

Pavoine, S. & Dolédec, S. (2005) The apportionment of quadratic entropy: a useful alternative for partitioning diversity in ecological data. *Environmental and Ecological Statistics*, 12, 125–138.

Petchey, O.L. & Gaston, K.J. (2002) Functional diversity (FD), species richness and community composition. *Ecology Letters*, 5, 402–411.

Petchey, O.L., Evans, K.L., Fishburn, I.S. & Gaston, K.J. (2007) Low functional diversity and no redundancy in British avian assemblages. *Journal of Animal Ecology*, 76, 977–985.

Pierce, G.J., Luzzaro, A., Caccianiga, M., Ceriani, R.M. & Cerabolini, B. (2007) Disturbance is the principal alpha-scale filter determining niche differentiation, coexistence and biodiversity in an alpine community. *Journal of Ecology*, 95, 698–706.

Pillar, V.D., Duarte, L.S., Sosinski, E.E. & Fernando, J. (2009) Discriminating trait-convergence and trait-divergence assembly patterns in ecological community gradients. *Journal of Vegetation Science*, 20, 334–348.

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D. & the R Core team (2009) *nlme: linear and nonlinear mixed effects models*. R package version 3.1-93

Poschlod, P., Tackenberg, O. & Bonn, S. (2005) Plant dispersal potential and its relation to species frequency and co-existence. In E. van der Maarel (Ed.), *Vegetation ecology* (pp. 147–171). USA: Blackwell Science Ltd.

Prinzing, A., Reiffers, R., Braakhekke, W.G., Hennekens, S.M., Tackenberg, O., Ozinga, W.A., Schaminee, J.H.J. & van Groenendael, J.M. (2008) Less lineages – more trait variation: phylogenetically clustered plant communities are functionally more diverse. *Ecology Letters*, 11, 809–819.

Pykälä, J., Luoto, M., Heikkinen, R.K. & Kontula, T. (2005) Plant species richness and persistence of rare plants in abandoned semi-natural grasslands in northern Europe. *Basic and Applied Ecology*, 6, 25-33.

Quinn, G.P. & Keough, M.J. (2002) *Experimental design and data analysis for biologists*. Cambridge University Press, Cambridge

R Development Core Team (2009). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Raatikainen, K.M., Heikkinen, R.K.& Pykälä, J. (2007) Impacts of local and regional factors on vegetation of boreal semi-natural grasslands. *Plant Ecology*, 189, 155-173.

Ricklefs, R.E. (1987) Community diversity: Relative roles of local and regional processes. *Science*, 235, 167–171.

Ricotta, C. (2005) A note on functional diversity measures. *Basic and Applied Ecology*, 6, 479–486.

Ricotta, C. & Szeidl, L. (2009) Diversity partitioning of Rao's quadratic entropy. *Theoretical Population Biology*, 76, 299–302.

Rook, A.J., Dumont, B., Isselstein, J., Osoro, K., WallisDeVries, M.F., Parente, G. et al. (2004) Matching type of livestock to desired biodiversity outcomes in pastures – A review. *Biological Conservation*, 119, 137–150.

Rübel, E., (1911) Pflanzengeographische Monographie des Berninagebietes. *Bot. Jahrb,*. 47, 1–616.

Rudmann-Maurer, K., Weyand, A., Fischer, M. & Stöcklin, J. (2008) The role of landuse and natural determinants for grassland vegetation composition in the Swiss Alps. *Basic and Applied Ecology*, 9, 494-503.

Sboarina, C., Cescatti, A. (2004) *Il clima del Trentino. Distribuzione spaziale delle principali variabili climatiche.* Report 33. Centro di Ecologia Alpina, Trento.

Sebastiá, M.T. (2004) Role of topography and soils in grassland structuring at the landscape and community scales. *Basic and Applied Ecology,* 5, 331-346.

Smith, R.S., Buckingham, H., Bullard, M.J., Shiel, R.S. & Younger, A. (1996) The conservation management of mesotrophic (meadow) grassland in Northern England. I. Effects of grazing, cutting and fertiliser on the vegetation of a traditionally managed sward. *Grass and Forage Science,* 51, 278–291.

Spiegelberger, T., Matthies, D., Müller-Schärer, H. & Schaffner, U. (2006) Scale-dependent effects of land use on plant species richness of mountain grassland in the European Alps. *Ecography*, 29, 541-548.

Stählin, A. (1971) *Guetezahlen von Pflanzenarten in frischem Grundfutter.* Dlg Verla, Frankfurt.

Stubbs, W.J. & Wilson, J.B. (2004) Evidence for limiting similarity in a sand dune community. *Journal of Ecology*, 92, 557–567.

Tasser, E. & Tappeiner, U. (2002) Impact of land use changes on mountain vegetation. *Applied Vegetation Science*, 5, 173–184.

ter Braak, C.J.F. & Šmilauer, P. (2002) *CANOCO Reference manual and CanoDraw for Windows User's guide: Software for Canonical Community Ordination (version 4.5).* Microcomputer Power, Ithaca.

Thompson, K., Hillier, S.H., Grime, J.P., Bossard, C.C. & Band, S.R. (1996) A functional analysis of a limestone grassland community. *Journal of Vegetation Science*, 7, 371–380.

Tichy, L., (2003) JUICE, software for vegetation classification. *Journal of Vegetation Science,* 13, 451-453.

Tichy, L. & Chytry, M. (2006) Statistical determination of diagnostic species for site groups of unequal size. *Journal of Vegetation Science,* 17, 809–818.

Tilman, D. (2001) Functional diversity. In: Levin, S.A. (ed.) *Encyclopedia of biodiversity*. Academic Press, San Diego.

Toigo, M. (1993-94) Caratterizzazione vegetazionale di prati e di pascoli delle Alpi oriental. Tesi di laurea in Scienze Forestali, Università degli Studi di Padova, Padova.

Vandvik, V. & Birks, H.J.B. (2002a). Partitioning floristic variance in Norwegian upland grasslands into within-site and between-site components: are the patterns determined by environment or by land-use? *Plant Ecology*, 162, 233-245.

Vandvik, V. & Birks, H.J.B. (2002b) Pattern and process in Norwegian upland grasslands: a functional analysis. *Journal of Vegetation Science*, 13, 123-134.

Vandvik, V. & Birks, H.J.B. (2004) Mountain summer farms in Røldal, western Norway – vegetation classification and patterns in species turnover and richness. *Plant Ecology*, 170, 203–222.

Veech, J.A., Summerville, K.S., Crist, T.O. & Gering, J.C. (2002) The additive partitioning of species diversity: recent revival of an old idea. *Oikos*, 99, 3–9.

Vickery, J. A., Tallowin, J. R., Feber, R. E., Asteraki, E. J., Atkinson, P. W., Fuller, R. J. & Brown, V.K. (2001) The management of lowland neutral grasslands in Britain: Effects of agricultural practices on birds and their food resources. *Journal of Applied Ecology*, 38, 647–664.

Wagner, H. H., Wildi, O., & Ewald, K. C. (2000) Additive partitioning of plant species diversity in an agricultural mosaic landscape. *Landscape Ecology*, 15, 219–227.

Weiher, E. & Keddy, P. (1995). Assembly rules, null models, and trait dispersion: new questions from old patterns. *Oikos*, 74, 159–164.

Westoby, M., Falster, D.S., Moles, A.T., Vesk, P.A. & Wright, I.J. (2002) Plant ecological strategies: some leading dimensions of variation between species. *Annual Review of Ecology and Systematics*, 33, 125–159.

Whittaker, R.J. (1975) *Communities and ecosystems*. Macmillan, New York.

White, T.A., Barker, D.J. & Kenneth, J.M. (2004) Vegetation diversity, growth, quality and decomposition in managed grasslands. *Agricultural, Ecosystems & Environment*, 101, 73–84.

Wildi, O. & Orlóci, L. (1996) *Numerical exploration of community patterns. A guide to the use of MULVA-5*. Ed. 2. SPB, Amsterdam, NL.

Wilson, J.B. (2007) Trait-divergence assembly rules have been demonstrated: limiting similarity lives! A reply to Grime. *Journal of Vegetation Science*, 18, 451–452.

Wohlgemuth, T. (1998) Modelling floristic species richness on a regional scale: a case study in Switzerland. *Biodiversity and Conservation*, 7, 159–177.

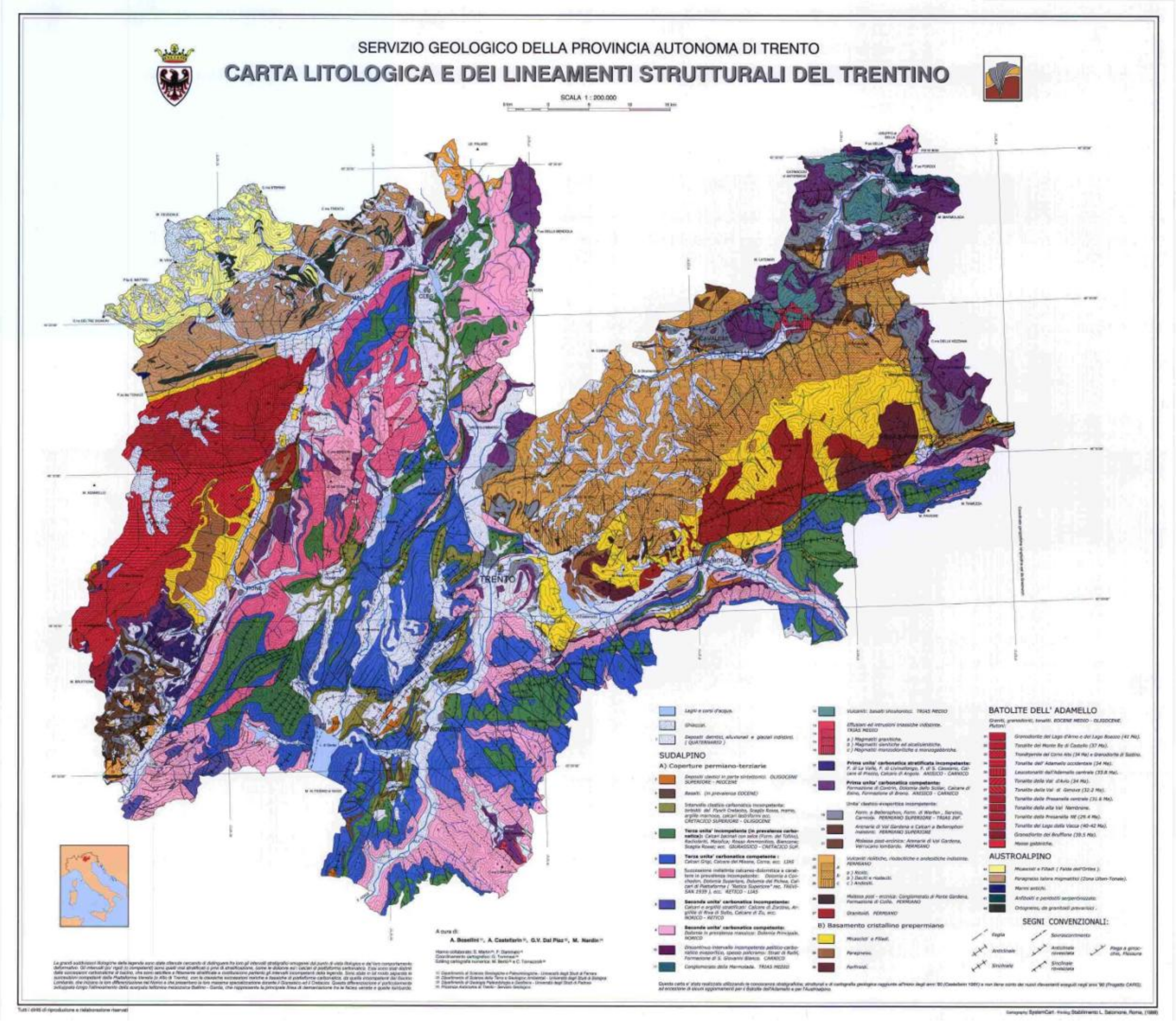
Wohlgemuth, T. & Gigon, A. (2003) Calcicole plant diversity in Switzerland may reflect a variety of habitat templets. *Folia Geobotanica*, 38, 443–452.

Ziliotto, U., Andrich, O., Lasen, C. & Ramanzin, M., (2004) *Tratti essenziali della tipologia veneta dei pascoli di monte e dintorni*. Regione Veneto, Accademia Italiana di Scienze Forestali, Venezia.

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A. & Smith, G.M. (2009) *Mixed Effect Models and Extensions in Ecology with R*. Springer-Verlag, Berlin

APPENDICES

APPENDIX A Geological map of the Province of Trento (Boselin et al. 1999).



APPENDIX B Pearson correlations between species richness with the factors tested a) at local scale (SLOPE, slope angle; DIST, distance from the farm centre; DSOIL, soil depth) and b) at regional scale (ALT, mean altitude; GRAZ, grazing intensity) in this study. *** $P < 0.001$; * $P < 0.05$; $^{n.s.}$ not significant.

a) Local scale

	Species richness		SLOPE		DIST	
SLOPE	0.339	***				
DIST	0.005	n.s.	0.005	n.s.		
DSOIL	0.068	n.s.	0.084	n.s.	0.151	n.s.

b) Regional scale

	Species richness		ALT	
ALT	0.730	***		
GRAZ	-0.343	n.s.	-0.502	*

APPENDIX C Pearson correlations between Simpson diversity components (α_s, β_s, γ_s) and functional diversity components (α_f, β_f, γ_f) with the factors tested in this study. Only significant values are shown ($P < 0.01$). Pearson correlation > 0.6 is signed in bold. Intercorrelated variables excluded after the analysis of the Pearson correlation matrix are presented in square parentheses. ALT, average altitude; CAL, area covered by calcareous bedrock; ACID, area covered by acid bedrock; FOR, area covered by forest; GRA, area covered by grasslands; ROCK, area covered by bare rock; TEM, mean annual temperature; ALT_H, altitude range; SLO_H, slope heterogeneity; GRAZ, grazing intensity.

	α_s	β_s	γ_s	α_f	β_f	γ_f	ALT	CAL	ACID	FOR	GRA	ROCK	TEM	ALT_H	SLO_H
β_s	0.48														
γ_s	**0.61**	**0.99**													
α_f	-	-	-												
β_f	-	-	-	-											
γ_f	-	-	-	**0.93**	**0.63**										
ALT	-	**0.67**	**0.61**	-	0.52	0.49									
CAL	**0.76**	0.45	0.54	-	-	-	-								
[ACID]	-0.53	-0.42	-0.48	-	-	-	-	**-0.84**							
FOR	-	**-0.62**	**-0.61**	-	-	-	-0.55	-	0.42						
[GRA]	-	0.46	0.47	-	-	-	-	-	-0.42	**-0.91**					
ROCK	-	0.54	0.55	-	0.49	-	0.59	-	-	-0.37	-				
[TEM]	-	**-0.66**	-0.60	-	-0.48	-0.46	**-0.98**	-	-	0.53	-	**-0.64**			
[ALT_H]	-	0.56	0.55	-	-	-	**0.61**	-	-	-0.45	-	0.53	**-0.62**		
SLO_H	-	**0.64**	**0.63**	-	-	-	0.48	-	-	-0.60	0.43	0.48	-0.51	**0.81**	
GRAZ	-	-	-	-0.48	-	-	-0.45	-	-	-	-	-	0.42	-0.40	-