UNIVERSITÀ DEGLI STUDI DI TORINO

The final publication is available at Springer via http://dx.doi.org/10.1007/s10531-013-0544-y

Differential responses of ground dwelling arthropods to ski-piste restoration by hydroseeding

Matteo Negro[1], Antonio Rolando[1]*, Elena Barni[1], Davide Bocola[1], Gianluca Filippa[2], Michele Freppaz[2], Marco Isaia[1], Consolata Siniscalco[1] and Claudia Palestrini[1]

*Corresponding author: tel. +39 011 6704533; fax: +39 011 6704508; E-mail: antonio.rolando@unito.it

[1]Dipartimento di Scienze della Vita e Biologia dei Sistemi, Università di Torino, via Accademia Albertina 13, 10123 Torino, Italy
[2]Dipartimento di Scienze Agrarie, Forestali e Alimentari, Università di Torino, via Leonardo da Vinci 44, 10095 Grugliasco (Torino), Italy

Abstract

The construction of ski-pistes can cause serious damage to all the components of an ecosystem and may therefore be considered as one of the main causes of human-driven environmental changes in mountain habitats. This study was aimed at assessing the responses of different ground dwelling arthropod assemblages (i.e. ground beetles, spiders and grasshoppers) to ski-piste restoration through hydroseeding with commercial seed mixtures. The soil, vegetation and arthropods of restored and un-restored ski-pistes and the adjacent grassland have been sampled at two high altitude sites in the north-western Italian Alps.

The ski-piste soil was characterized by a higher skeletal content and, consequently, a lower amount of fine earth and organic matter than that of the undisturbed adjacent grassland. The plant cover of the restored ski-pistes was very low above 2500 m a.s.l.; the vegetation cover below this threshold was higher in the study area, mainly due to the seeded species. The unrestored ski-pistes showed very large proportions of bare ground.

The responses of the three ground-dwelling arthropod groups to vegetation conditions were different. GLMMs and IndVal analyses showed that all three groups avoided the unrestored ski-pistes plots, which were characterized by a very scarce vegetation cover, irrespective of the altitude. The low altitude plots of the restored ski-pistes, which were characterized by a high vegetation cover, had a significantly larger number of grasshoppers on the ski-pistes than on the adjacent grassland plots. Moreover, these restored ski-piste plots were used in equal proportion to the adjacent grassland plots by ground beetles but avoided by spiders.

When ski-pistes become sufficiently revegetated by hydroseeded plants, they are colonized by grasshoppers and, to a lesser extent, by ground-beetles. Spiders, instead, do not colonize the pistes, thus demonstrating that they are the most sensitive arthropods and may therefore represent the best indicators of human-driven environmental changes in high altitude alpine habitats.

Introduction

The European Alps, like many mountain systems in the world, have to face multiple and increasing pressure on biodiversity due to the significant loss and degradation of natural or semi-natural habitats (EEA 2010), because of changes in land use (Laiolo et al. 2004) and in climate (e.g. Wilson et al. 2005; Pauli et al. 2007), as well as increasing human disturbance (Arlettaz et al. 2007; Thiel et al. 2007; Patthey et al. 2008).

Skiing, in particular, represents a significant threat to local biodiversity because it leads to changes in land use that can significantly modify the characteristics of a habitat. The skiing industry is of major economic importance in the alpine region, and it has recently experienced a period of great expansion (Abegg et al. 1997; Elsasser and Messerli 2001; Wipf et al. 2005). Several thousands of kilometers are used for downhill skiing in the Alps (Rolando et al. 2007) and in the Swiss Alps alone 220 km^2 are directly affected by ski-pistes (Amacher-Hoppler and Schoch 2008). The area above the treeline is of particular concern, because climate changes will probably induce operators and stakeholders to shift skiing activities and ski-pistes to higher altitudes (Elsasser and Messerli 2001; Fukushima et al. 2002, Bicknell and McManus 2006; Scott et al. 2008) where very sensitive ecosystems exists (Körner 1999). The main impact of ski-slopes is on vegetation and soils, since the natural vegetation and most of the upper soil horizons are removed during the construction process (machine grading), to provide suitable slopes for skiers and to enhance the use of artificial snow (Mosimann 1985; Wipf et al. 2005; Isselin-Nondedeu and Bédécarrats 2007; Delarze and Gonseth 2008). After machine grading, ski-piste soils become mineral substrates with a low organic matter content and poor water holding capacity (Krautzer et al. 2006; Burt and Rice 2009). The altered soils, the harsh climatic conditions and the alpine plant species traits limit the development of the vegetation cover, thus leading to erosion and a further loss of soil organic matter. The control of erosion through the development of the plant cover is one of the essential aims of ski-piste restoration. The most challenging technique used to establish a vegetation cover at high altitudes is hydroseeding. The outcome of this restoration practice depends to a greater extent on the seed mixtures that are used and these are usually made of commercial grasses and legumes. Commercial mixtures are usually successful in producing a plant cover over the first few years, but often fail in the medium-long term, since a self-sustaining vegetation cover is only guaranteed through the use of ecologically adapted alpine species (Krautzer et al. 2013; Klug et al. 2013). For this reason, several efforts have been made to obtain high altitude adapted seed species, in order to establish a functionally sustainable and diverse plant community improving ecosystem functions and services (Burt 2012 and references therein). The results of the use of alpine species for revegetation purposes have progressively been limited along the altitudinal gradient, confirming that the plant traits of the alpine species and in particular their very low growth rates, the production of a very low number of seeds and the insufficient agents of seed dispersal (Urbanska and Fattorini 2000), result in severe restoration difficulties at higher altitudes (Klug et al. 2013).

Several papers concerning the impact of high altitude ski-pistes on animals, especially arthropods, have been published (Haslett 1988; Illich and Haslett 1994; Kopeszki and Trockner 1994; Rolando et al. 2007; Negro et al. 2010; Caprio et al. 2011; Kessler et al. 2012).

Ground dwelling arthropods in particular are disturbed because of the removal of soil and alpine vegetation. The low grass cover of ski-pistes is a serious hindrance to colonization by spiders, grasshoppers, and some carabid species (Negro et al. 2010). The impact of ski-pistes on such arthropods is of concern because of their prime importance for alpine ecosystem functioning. For instance, spiders and most ground beetles are predators that play a key role in regulating populations of soil invertebrates and serve as prey for salamanders, small mammals and birds (Clarke and Grant 1968; Hance 1990). Grasshoppers are primary consumers in most grasslands. Their importance in removing biomass and accelerating nutrient turnover has been demonstrated in alpine grassland (Blumer and Diemer 1996) where, during the summer, they become an important resource for typical alpine birds (Rolando and Patterson 1993; Rolando and Laiolo 1997).

It can therefore be stated that the construction of ski-pistes can cause serious damage to all the components of an ecosystem, i.e. soil, vegetation and animals. Studies on the impact of ski-pistes have mostly been concentrated on soils (Freppaz et al. 2002; Gros et al. 2004; Pintar et al. 2009), and on vegetation (Delarze 1994; Van Ommeren 2001; Wipf et al. 2005), or, more rarely, on the combination of soil and vegetation (Barni et al. 2007; Pohl et al. 2009; Martin et al. 2010; Roux-Fouillet et al. 2011). The studies conducted on animals have not considered soil, and have only taken into account vegetation marginally (Laiolo and Rolando 2005; Rolando et al. 2007; Caprio et al. 2011; Negro et al. 2009, 2010, 2013; Rolando et al. 2013). In this study, all three components of alpine ecosystems have been considered together for the first time. Two high elevation sites (2400-2700 m a.s.l.) at the top end of the same valley in the north-western Italian Alps have been focused on. The ski-pistes at the first site were hydroseeded in 1997 using commercial seed mixtures (henceforth reported as *restored* ski-pistes), whereas the ski-pistes at the second site were not hydroseeded (*unrestored* ski-pistes). A paired design of plots on the ski-piste and the adjacent control plots on natural grassland to sample soil, vegetation and arthropods, was used to assess the impact of ski-piste construction on all three components of the local alpine ecosystem. In this framework, attention was in particular focused on the responses of three different groups of ground-dwelling arthropods (ground beetles, grasshoppers and spiders) to ski-piste restoration by means of hydroseeding, through a comparison of the restored and unrestored ski-pistes. The aim was also to single out warning indicators, that is, taxa (arthropod groups or single species) that are extremely sensitive to changes in environmental conditions.

Material and Methods

STUDY AREA

The study was conducted on high altitude ski-pistes at the top end of the Lys Valley (Gressoney-la-Trinité resort), in the north-western Italian Alps (Aosta Valley, 45°51'22''N; 7°50'41''E, Fig.1). The survey area is within one of the most important ski-districts of the Alps (Monterosa Ski), with 180 km of ski-pistes and an hourly flow of more than 50000 people (www.monterosa-ski.com). The climate is continental with the mean temperatures varying from -3.6°C in the coldest month (January) to 12.7°C in the warmest month (July). The annual rainfall (1202 mm average) can be defined as ''Sub-litoraneo alpino'' with two maxima in May and October and two minima in July and December–January (Mennella 1972).

Pistes below the Bettaforca pass (between the pass and S. Anna) and the Salati pass (between the pass and the Gabiet lake) were studied. The ski-pistes were located above the timberline, between 2430 and 2750 m a.s.l., and they crossed typical alpine grasslands dominated by *Nardus stricta Carex curvula* and *Poa alpina* graminoids and forbs such as *Arnica montana, Geum montanum, Pulsatilla alpina* and *Trifolium alpinum*. The environmental conditions on the slopes above 2600 m a.s.l. limit the formation of soil and continuous grassland, and the ski-pistes cross patches of alpine prairies that alternate with debris.

The ski-pistes in the two sites are managed differently. The Bettaforca ski-pistes (1 main piste with several lateral ones) were hydroseeded in 1997 with a commercial mixture composed of *Festuca rubra* (50 %), *F. rubra commutata* (10 %), *F. longifolia* (15 %), *Phleum pratense* (10 %), *Trifolium repens* (5 %), *T. pratense* (5 %) and *Lotus corniculatus* (5 %). A mineral fertilizer was supplied during the hydroseeding (N/P/K 12/12/12, 30–40 g m^2), and manure was added once. The Salati ski-pistes (1 main piste with several lateral ones) instead were not hydroseeded.

SAMPLING DESIGN

Soil

The soil was only sampled at the Bettaforca site, in the summer 2009. Samples were collected in five plots along an elevation gradient between 2200 and 2600 m a.s.l.. Two subplots in each plot, were established at comparable conditions (slope and aspect), one in the ski-pistes and one in the adjacent undisturbed alpine pastures. Soil profiles were described in both the ski-pistes and in the undisturbed sites and classified according to the USDA Soil Taxonomy (Soil Survey Staff 2010). The uppermost soil samples (0-10 cm depth), corresponding to the A horizons, were sampled and analysed for carbon (C) and nitrogen (N) content (CN analyser, CE Instruments, NA2100 Protein, Milan, Italy), gravimetric water content (after oven drying), pH (1:10 soil:water ratio, Ion 83 Ion Meter), bulk density (BD), extractable ammonium (NH4+, Bremner 1965; Crooke and Simpson 1971), and nitrate (NO3-, Crooke and Simpson 1971).

Vegetation and arthropods

The vegetation and arthropods were sampled together, at the Salati site in the summer of 2007 and at Bettaforca in the summer of 2010. The arthropod data collected at the Salati site were also used in a previous paper (Negro et al. 2010). Four altitudinal sampling zones were established along the ski-pistes on the basis of physionomic vegetation differences: zone 1, between 2640 and 2750 m a.s.l.; zone 2, between 2530-2640 m a.s.l.; zone 3, between 2480-2530 m a.s.l. and zone 4, 2430-2480 m a.s.l (Fig.1). Three pairs of plots were randomly located in each sampling zone. Each pair included one 10 x 10 m plot located on the ski piste and one control plot of the same size located outside the ski-piste (about ten meters) in the adjacent undisturbed natural grassland at the same altitude, and with the same exposure and slope. A total of 12 pairs of plots were therefore sampled for each site for both the arthropods and vegetation.

Sampling of vegetation

The vegetation parameters were recorded in a 2 x 2 m subplot randomly chosen within each 10 x 10 m plot. The following parameters were recorded in each subplot: occurrence and cover (%) of each vascular plant species, total vegetation cover (%), moss cover (%), bare soil (%), dry matter cover (%), and vegetation height (cm) expressed as the mean of 4 random measurements. The

cover percentage values and the percentage area of bare soil were estimated visually. Species richness and plant species diversity (Shannon Index) were calculated for each subplot.

Sampling of ground-dwelling arthropods

Four pitfall traps were placed in a square pattern in each 10 x10 m plot, therefore leading to a total of 96 pitfall traps in each sampling site [4 zones x 2 habitats (natural grassland, ski-piste) x 3 plots x 4 pitfall traps].

The mouth diameter of the pitfall traps was 7.5 cm and they were 9 cm deep. Four small holes (0.2 cm in diameter) were drilled 2.5 cm below the upper brim of the pitfall, so that excess rainwater could flow out. Each trap was filled with 150 ml of a mixed fluid (vinegar and salts) to preserve individuals (van den Berghe 1992). A flat stone was placed 3 cm above each trap to prevent rainwater from entering the traps. The exact location of the pitfall traps was established in the field by means of a Garmin eTrex Global Positioning System (GPS) navigator. The pitfall traps were installed in July and emptied on two week basis until the end of September.

Ground beetles, grasshoppers and spiders were sorted and identified, whenever possible, to a species level using updated standard keys or specialist works. Nomenclature follows Platnick (2013) for the spiders, Audisio and Vigna Taglianti (2004) for the ground beetles and Fontana et al. (2005) for the grasshoppers.

DATA ANALYSIS

Soil

The soil data were analysed using a two-way permutation analysis of variance, with R software (R Development Core team 2012) and the *lmPerm* (Wheeler 2010) and multcomp (Hothorn et al. 2008) Packages. The factors included in ANOVA were habitat type (grassland and ski-piste) and elevation (two levels of altitude, above and below 2400 m a.s.l).

Vegetation

The multivariate relationships between the seven vegetation variables measured on each 2 x 2 m subplot [dry matter cover, moss cover, vegetation cover, bare soil cover, species richness, vegetation height and Shannon plant diversity (expressed as $H' = -\sum p_i \times \log_2 p_i$ where p_i is the relative frequency of species i)] were explored in R (R Development Core team 2012) using the *BiplotGUI* package (LaGrange et al. 2009).

The results are displayed as a Principal Component Analysis (PCA) biplot, where the variable loadings on the first two principal components are used to define vectors that provide a graphical representation of the relationships between the variables. The variate biplot on these two dimensions illustrates the direction in which the values of each variable in the dataset move relative to each other. The vectors cross at the origin (zero) of the axes, which is defined by the principal components, and represent the overall mean values. In the diagram of Axis predictivities, the further right a vegetation variable appears, the better it is represented in the first (or horizontal) biplot dimension (PC1). The closer the variable is to the top of the diagram, the better it is represented overall in the biplot, if the contribution of both the first and the second biplot dimension (PC1 + PC2) is taken into account. The marginal contribution of the second principal component is indicated by the vertical distance between the diagonal line and the variable (LaGrange et al. 2009).

In order to analyse how the percentage cover of each species differs according to site, zone, and habitat (grasslands and ski-pistes), a Detrended Correspondence Analysis (DCA, Hill and Gauch 1980) was performed using R software with the vegan package (Oksanen et al. 2005; R Development Core team 2012). In this case, DCA was used because PCA with species data sets suffers from an "arch effect or horseshoe effect" due to the fact that species often have unimodal species response curves along environmental gradients (Legendre and Legendre 1998). Hill and Gauch (1980) proposed DCA as a solution for the arching problem.

Ground-dwelling arthropods

1. *Species overlap*

The species overlap between the natural grasslands and ski-pistes was described for each zone in each site, using a ternary plot (Koleff et al. 2003), where the presence ∕ absence of species in a focal habitat (grassland) compared to each neighbouring habitat (ski-pistes) was considered. The number of species that were present in both habitats was considered as the pairwise matching component a. The number of species that were only present in the neighbouring habitat (ski-pistes) was b, while the number only present in the focal habitat (grassland) was c (Raes et al. 2007). The total number of species for the pair of habitats was therefore a + b + c; in percentage terms, this means a' + b' +c' = 100%.

2. *Diversity differences between natural grasslands and ski-pistes*

The abundance and species richness of spiders (respectively N_ARA and R_ARA) and orthoptera (N_ORT; R_ORT) were computed for each pitfall trap (the trap was therefore the basic sample unit). The ground beetle assemblages could have been composed of species with contrasting ecological requirements so that ecological patterns could not be appropriately revealed (Negro et al. 2009, 2010). Accordingly, the carabids were divided into three ecological groups on the basis of their wing morphology: macropterous (full-sized wings), brachypterous (reduced wings or wingless) and wing-dimorphic (species with both winged and short-winged individuals). The data on flight ability were obtained from literature (Brandmayr et al. 2005). However, since there were very few wing-dimorphic species individuals, this ecological group was excluded from the statistical analyses. Abundance and species richness for macropterous (N_MAC; R_MAC) and brachypterous species (N_BRA; R_BRA) was therefore computed separately for each trap.

All the diversity parameters (N_ARA, R_ARA, N_ORT, R_ORT, N_MAC, R_MAC, N_BRA, R_BRA) were related to the categorical, explanatory variable ''habitat type'', via Generalized Linear Mixed Models (GLMMs, Zuur et al. 2009) in the R environment (R Development Core Team 2012), to test for differences between the grasslands and ski-pistes in each sampling zone, GLMMs were used to account for the lack in normality of the dependent variables. This mixed procedure allowed a temporal variable (sampling period) to be included as a random factor in order to account for the variation that the variables introduced into the samples (and thus to correctly estimate the regression coefficients for habitat types), rather than to test for their direct effect on the dependent variables (as in Paschetta et al. 2012). The resulting structure of the model was:

$$Y \sim HT + (1 / period)$$

where y = one of the diversity parameters (N_ARA, R_ARA, N_ORT, R_ORT, N_MAC, R_MAC, N_BRA, R_BRA); HT = habitat type (fixed effect). The random part of the model includes the effect of the temporal grouping variable (sampling period). A Poisson distribution was assumed for the abundance and richness data (i.e. count data), but, after having tested for overdispersion prior to model fitting (via the *qcc* package—Scrucca 2004), it was decided to fit the GLMMs assuming a negative binomial distribution, where appropriate.

The regression models were fitted by means of the glmmAMDB (Fournier et al. 2012) R package, selecting the natural grassland habitat type as the reference category. The outcome of the models thus consisted of regression coefficients for the remaining habitat type (ski-piste). These coefficients express the result of pairwise comparisons with the reference category, whose significance was assessed via Wald tests (Dobson 1990).

3. *IndVal procedure*

The high specificity and fidelity of each arthropod species was explored between habitats (natural grassland and ski-piste) by means of the IndVal (Indicator Value) procedure (Dufrêne and Legendre 1997) considering the four altitudinal zones in both sampling sites separately. The indicator value was maximum when all the individuals of a species were found in a single habitat (high specificity) and when the species occurred in all the samples (in the present study, the traps) of that habitat (high fidelity). The statistical significance of the maximum indicator value was evaluated by means of a Monte Carlo randomization test (1,000 runs). The indicator species analysis was conducted using R software with the *labdsv* package (Roberts 2010; R Development Core Team 2012).

RESULTS

Soil

The ski-piste soil was clearly different from that of the adjacent natural grassland. The skeletal content and the bulk density in the A horizons were significantly higher in the ski-pistes than in the adjacent grasslands (p<0.001 and p<0.01, respectively). Conversely, the carbon and the ammonium contents were higher in the grasslands than in the ski-pistes (p<0.001 and p<0.05, respectively). Moreover, when considering the complete soil dataset, soil depth was significantly negatively correlated to elevation (r=-0.809; p<0.01), as was the depth of the B horizon (r=-0.973; p<0.05).

Vegetation

The Principal Component Analysis, used to explore the multivariate relationships between the seven vegetation variables (60% of the variation in the dataset was accounted for by the first two dimensions), and DCA, used to consider variation in species composition, both gave useful information on the similarity or dissimilarity of the grasslands and ski-pistes at the two sites. As for as PCA is concerned, the axis predictivities diagram showed (Fig. 2) that the vegetation cover, Shannon diversity and the number of plant species were the best represented variables in the first

dimension (PC1) and the best represented overall variables in the biplot, taking into account the contribution of both the first and the second dimensions (PC1 + PC2).

The vegetation of the natural grasslands was very similar in the two sites. The Bettaforca and Salati centroids, relative to the grasslands, were placed all together on the right side in the PCA biplot (Fig. 3), hence suggesting that the grasslands in the two sites were rather homogeneous (no significant differences were detected in the Mann-Whitney U-tests for any vegetation variable). The original variable values along each vector indicated that the natural grasslands were characterized by a high plant cover (ranging from about 60 to 90%), high species richness (about 25 species), a Shannon Index ranging from 1.5 to 2.5 and taller vegetation than 7.5 cm. The great plant homogeneity of the grasslands at the two sites was also confirmed by the DCA on the percentage cover of each species. The Bettaforca and Salati centroids, relative to the grasslands were placed together in the center-left side of the DCA plot (Fig. 4), near typical alpine pasture species such as *Carex sempervirens*, *Nardus stricta*, *Trifolium alpinum*, *Geum montanum* and *Pulsatilla alpina*, all of which were characterized by high cover percentages.

The vegetation of the ski-pistes was very different from that of the adjacent grassland because of the poor vegetation cover at higher altitudes or the presence of hydroseeded plants at lower altitudes. In the multivariate analyses, the centroids of the ski-pistes were set apart from the centroids of the grasslands in both PCA (Fig. 3) and DCA (Fig. 4). Contrary to what was observed for the natural grasslands, the structure of the vegetation of the ski-pistes was clearly different in the two sites., The centroids relative to Salati were found on the left in the PCA biplot (Fig. 3), whereas those relative to Bettaforca were found on the upper side. The unrestored Salati ski-pistes were characterized by a low vegetation cover (about 25%) and a corresponding high percentage of bare soil (about 75%), low species richness (about 9), low Shannon index (about 0.7) and low vegetation height (about 4 cm). The restored Bettaforca ski-pistes were characterized by a higher vegetation cover (above 20%), and with taller plant species (about 10 cm) while the Shannon diversity and species richness were similar to the unrestored Salati ski-pistes.
The differences between the high (zones 1 and 2) and low (zones 3 and 4) altitude zones at Bettaforca were apparent in the field, especially since the vegetation cover was low in the former and much higher in the latter. These differences were mirrored in the PCA biplot, with the centroids of zones 1 and 2 of Bettaforca being set near the centroids of Salati, whereas the centroids of zones 3 and 4 were not far from those of the natural meadows. Non-parametric tests confirmed the altitudinal differences for the moss cover (Mann-Whitney U-test; $z= 2.75$, $P<0.05$), which was higher at higher altitude, for vegetation cover (Mann-Whitney U-test; $z= -2.40$, $P<0.05$) and for the height of vegetation (Mann-Whitney U-test; $z= -2.72$, $P<0.05$), which was higher at lower altitude.
The plant community composition of the ski-pistes was also clearly different for the two sites (Appendix 1). The unrestored Salati ski-pistes were colonized by very few plants that are typical of debris, while the restored Bettaforca ski-pistes were revegetated by seeded native commercial species, such as *Festuca rubra*, *Trifolium pratense*, *Trifolium repens* and *Trifolium hybridum*, which, except for *Festuca rubra*, were absent in the natural grasslands (Appendix 1). This picture reverberates on the DCA biplot (Fig. 4), with the Salati centroids being located at the center of the plot distant from any plant species, whereas the Bettaforca centroids were placed on the right, and were encompassed by hydroseeded species.

Ground dwelling arthropods

Arthropod assemblages

A total of 2667 individuals, belonging to 39 different species (21 species of carabids, 14 species of spiders and 4 species of grasshoppers), were collected in the Salati site. Carabids were numerically predominant, as they accounted for 67.6% of the total number of individuals, and were followed by spiders (23.6%), and grasshoppers (8.8%). In the Bettaforca site, 1674 individuals, belonging to 38 different species were trapped: 18 carabids, 15 spiders and 5 grasshoppers (Appendix 2). The arthropod community, as a whole, was dominated by carabids (48.7%), followed by grasshoppers (30%) and spiders (21.2%). The majority of the most representative taxa (25 species in the sample) was found in the two sites. The complete list of the arthropod species can be found in Appendix 2.

Some species were considered of conservation interest because they are precinctive (or endemic) to restricted geographic areas. Six species are endemic to the Alps (*Ocydromus rhaeticus* and *Oronebria picea* among the ground beetles; *Anonconotus alpinus* among the grasshoppers; *Zelotes devotus, Meioneta alpica* and *Sitticus longipes* among spiders) and seven are restricted to the western part of the chain (*Carabus concolor, Carabus latreilleanus, Cychrus cordicollis, Platynus complanatus, Pterostichus cribratus,* and *Pterostichus parnassius* among the ground beetles; *Coelotes pickardi pickardi* among the spiders).

Species overlap

The Salati ternary plot showed very low percentages of species exclusive to the ski-pistes, regardless of which group or zone was considered. All the dots were in fact distant from the b' vertex, which means that the b'component was small, and hence that these were few species exclusive to the ski-pistes (Fig. 5). The Bettaforca ternary plot showed a certain increase in species exclusive to the ski-pistes at a lower altitude. The dots representing the spiders and macropterous carabids in zone 4, for instance, were found closer to the b' than the c' vertex, which means that there were more species exclusive to the ski-pistes than species exclusive to the grassland (Fig. 5).

Diversity differences between natural grasslands and ski-pistes

A significant overdispersion (overdispersion test, qcc, p<0.001 for all parameters) was detected for the abundance parameters (N_BRA, N_MAC, N_ARA, N_ORT) and models were thus fitted assuming a negative binomial error distribution. Poisson models were fitted for the richness (i.e. number of species) data (R_BRA, R_MAC, R_ARA, R_ORT) since the ratio between the observed and theoretical variance approached the unit value assumed in the Poisson distribution.

The results showed that most of the ground dwelling arthropods at Salati avoided, or rarely used, the ski-pistes. In fact, N_BRA, N_ARA and R_ARA were significantly higher in the natural grassland (set as the reference category) than in the ski-pistes in all the altitudinal zones considered, and the same trend was evident for N_ORT and R_ORT in the lower zone (Table 1).

Conversely, the responses of arthropods at the Bettaforca site, diverged significantly. Spiders continued to avoid the ski-pistes in all the altitudinal zones, with N_ARA and R_ARA always being significantly lower on the ski-pistes than on the natural grassland. Carabids avoided ski-pistes only at a high altitude, where the abundance of both ecological groups (N_BRA, N_MAC) and the number of macropterous species (R_MAC) were significantly lower on ski-pistes than on natural grassland. Finally, grasshoppers, like spiders and carabids, significantly avoided the ski-pistes in the higher zones (1 and 2), but preferred the ski-pistes in the lower ones (3 and 4), where the estimates changed from negative to positive (Table 1).

In order to graphically display the peculiar selective trend depicted above, we calculated for each group and zone the differences between the mean values of abundance and species richness in grasslands and those in ski-pistes. At Salati, differences were usually positive because grasslands housed more individuals and species than ski-pistes for any group (macropteros ground beetles a part) and zone (Fig. 6). At Bettaforca, conversely, differences remained positive for spiders only, but reversed to weakly negative for ground beetles and strongly negative for grasshoppers in the lowest zones (Fig. 7), indicating that ski-pistes of lower altitude were more attractive than natural grasslands for ground beetles and, especially, for grasshoppers.

Indicator species

Indicator species for habitat type (natural grassland *vs*. ski-piste) were detected through the Indicator Value Procedure. In general, species that significantly preferred ski-pistes were less numerous than those preferring natural grasslands, but the lack of balance was more evident at Salati where 10 species were indicators of natural grassland in at least one zone and 3 species were indicators of ski-pistes. At Bettaforca 7 species were indicators of natural grassland and 4 of ski-pistes (Table.2).

Three species were shared between sites: the spider species *Pardosa mixta* always selected natural grassland (in the zones 2,3,4); the brachypterous ground beetle *Carabus concolor* was mostly an indicator species for natural grassland, with the noticeable exception of the zone 4 at Bettaforca, where it reversed its preference for ski-pistes; the grasshopper *Aeropus sibiricus* preferred natural grassland at Salati and ski-pistes at Bettaforca (zone 4).

Discussion

This study assessed the different responses of ground dwelling arthropods to differently managed ski-pistes, that have been restored by hydroseeding or unrestored.

The effects of the ski-pistes on the soil have been severe and results may presumably be extended to both sites, even though the sampling was only carried out at Bettaforca. The present analyses have shown that the soil of the ski-pistes was significantly different from that of adjacent grasslands. A higher skeletal content, and consequently, a lower amount of fine earth was found in the ski-pistes, suggesting that their construction has led to pedo-turbation, with the moving of some stony material upwards from the sub-surface and a consequent increase in its content in the A horizons. Accordingly, less organic matter has been found in the upper organo-mineral horizons (A) of the ski-slopes compared to the grasslands, suggesting either a lower organic matter accumulation, due to a lower biomass production in the ski-slope soil, or a stronger dilution of the former soil organic matter caused by mixing mineral and organo-mineral horizons during the ski-slope construction process. These results are in keeping with those reported in previous papers (Freppaz et al. 2002; Gros et al. 2004; Barni et al. 2007; Pintar et al. 2009; Pohl et al. 2009; Martin et al. 2010; Roux-Fouillet et al. 2011). Moreover, most of the soil properties in both the ski-pistes and in the grasslands seemed to be closely related to elevation. In particular the total soil depth and the depth of the B horizon significantly decreased at higher elevation, revealing how harsh environmental conditions may influence soil development.

The impact of ski-piste construction was also severe on vegetation. The unrestored ski-pistes at Salati were characterized by a poor vegetation cover and by the presence of very few plants that are typical of debris. Natural recovery, which depends on seed immigration from neighboring vegetation and/or more distant areas (Urbanska and Fattorini 2000), was nearly almost totally absent at Salati partly because of the pedo-turbation of the soil and the shallow soil depth found at

the high elevation. These results confirm that the revegetation process of high altitude ski-pistes is difficult, slow and does not lead to a sustainable community (Barni et al. 2007; Roux Fouillet et al. 2011). The impact of ski-piste construction may be mitigated by hydroseeding, a useful technique to create a fast soil cover which can counteract erosion and reduce the negative visual impact of bare ground. The present study has revealed that the vegetation cover of the restored ski-pistes at Bettaforca suffered from two remarkable limitations: it only grew below the altitudinal threshold of 2500 m, and very few individuals and species coming from the adjacent alpine grassland occurred with the seeded ones. Therefore a hydroseeding intervention that was carried out in 1997, several years later produced, ski-pistes that were still predominantly un-vegetated above 2500 m a.s.l. and which were vegetated by commercial plant species that were native, but different from the species growing in the local surrounding communities, below 2500 m a.s.l.

The main aim of this study was to assess the responses of ground dwelling arthropods to a hydroseeding restoration intervention. The richness and abundance of these arthropod groups can be influenced by several biotic and abiotic factors such as vegetation structure, plant productivity and microclimate conditions as well as the physical disturbance of habitats due to anthropogenic activities (Perner et al. 2005). Several studies, especially in agro-ecosystems, have predicted that arthropod abundance is influenced by plant diversity, although the results so far have been unclear and equivocal (Risch et al. 1983; Andow 1990; Koricheva et al. 2000; Perner et al. 2005, Schaffers et al. 2008). On the other hand, nutrients and the physical habitat condition, such as plant structural complexity or height of vegetation, can increase arthropod abundance significantly (Kyto et al. 1996; Kruess and Tscharntke 2002; Brose 2003). However, the biotic factor that most successfully predicts arthropod community structure is still a matter of debate and it is likely that the drivers are different for different ecosystems and taxa. Other studies have suggested that vegetation cover for ski-pistes is the main driver of the presence of these arthropods, which avoid ski-pistes characterized by low vegetation cover (Negro et al. 2010). The present results confirm that the percentage and type of vegetation cover are important factors that influence the abundance and species richness of ground dwelling arthropods. Both the GLMMs and species overlap ternary plots have indicated that all three ground-dwelling arthropod groups avoided ski-pistes in the sites or zones with a low vegetation cover and high bare soil percentage. However, the responses of these groups to successful restoration by hydroseeding, namely high cover of hydroseeded species, were clearly different.

The diversity of grasshoppers was significantly lower in the plots of the ski-pistes with a low vegetation cover, but significantly higher in the plots of restored ski-pistes with a higher vegetation cover consisting of hydroseeded grasses. Several factors have been shown to influence the diversity of Orthoptera, including microclimate variables (temperature, humidity, light intensity, etc.), availability of food, structural qualities, oviposition sites, suitable hiding places, and the presence of predators (Joern 1982). Several studies have examined the relationship between grasshopper assemblage composition and vegetation patterns in grassland ecosystems throughout the world (Kemp et al. 1990; Fielding and Brusven 1993; Wachter et al. 1998; Torrusio et al. 2002). Although plant diversity and vegetation structure often positively affect grasshopper diversity, in most grassland ecosystems it is still not completely clear which vegetation characteristics are the most important (Haddad et al. 2001; Joern 2005). Grasshoppers are mainly phytophagous insects: in the present work, it has been hypothesized that seeded plants provide more trophic resources than natural grassland for alpine grasshopper species in efficiently restored ski-pistes with a homogeneous vegetation cover and a greater plant biomass.

The diversity of brachypterous carabids was significantly lower in the ski-pistes with a low vegetation cover than in the neighbouring natural grassland, but there were no significant

differences in the restored ski-pistes, especially in the lower altitude zones (< 2500 m a.s.l.), with a higher vegetation cover and significant growth of seeded grasses. These results are in agreement with the "structural heterogeneity hypothesis" according to which it is the structural heterogeneity of the vegetation rather than the taxonomic diversity of the plants, is the most important driving factor for large-bodied brachypterous carabids (Brose 2003). In fact, large species (i.e. *Carabus concolor*, *C.latreinneanus*, *Pterostichus cribratus*) are more vulnerable to predation on the open plots and prefer dense vegetation, which can be found both in natural grasslands and in restored ski-pistes, to escape from natural enemies. No clear trend was observed for macropterous carabids. The differences in abundance and species richness between the two habitat types were almost never significant (with the exception of the upper zones in the Bettaforca site) for this ecological group. This result could be the consequence of the great dispersal power of these animals: macropterous carabids are known to be able to fly over large distances (den Boer 1970) and can thus easily and quickly reach ski-pistes from the neighbouring natural grassland.

The diversity of spiders remained significantly lower on the ski-pistes than on the adjacent grassland, regardless of the vegetation condition of the ski-pistes. The main proximal factors that affect the use of a microhabitat by spiders are microclimate, habitat structure, disturbance, prey availability, predation, and territoriality (Pearce et al. 2004). According to Samu (1999), the selection of microhabitats by individual spiders reflects a specific biological need or collection of needs, or reflects the avoidance of some factor, such as interspecific encounters. The spider may, for example, assess a microhabitat as a potential web site, oviposition site, overwintering site, or as a safe haven from predators during the inactive phase of a diel cycle, and these microhabitat needs may vary over time (Pearce et al. 2004). These two points of view suggest that neither unrestored nor restored ski-pistes present the structural and microclimatic conditions that alpine spider species need (but which can be found in neighbouring natural grassland).

In short, when ski-pistes become sufficiently revegetated, due to hydroseeding, they are particularly suitable for grasshoppers, but less so for ground-beetles. Spiders do not select ski-pistes at all irrespective of whether they are hydroseeded or not.

Another aim of this study was to single out indicators, that is taxa (arthropod groups or single species) which are extremely sensitive to changes in environmental conditions. The present results have demonstrated that spiders, due to their high sensitivity, are the best candidates to evaluate the effects of the construction and management of high altitude ski-pistes. In particular *Pardosa mixta* can be considered an indicator species (identified by IndVal Analysis) for natural grasslands, in both sites (Salati and Bettaforca), regardless of the vegetation cover of the ski-pistes and elevation. Ground beetles are also used as signalers. Several studies have documented changes in carabid assemblages due to habitat alteration such as forestry, wildfire, fragmentation and so on (Lövei and Sunderland 1996; Kromp 1999; Niemelä et al. 2007), although the responses have not always been clear. Another problem is that in many of these studies, carabids did not act as early warning indicators because they did not indicate any environmental alterations before they became visible to the naked eye (Koivula 2011). Despite these limitations, in this study area *Carabus concolor*, a brachypterous carabid species endemic to the Monte Rosa Massif, responded very well to the different vegetation conditions (IndVal Analysis). In the unrestored ski-pistes at Salati, *C. concolor* always selected natural grassland, whereas in the restored ski-pistes at Bettaforca, this species selected the natural grassland at a high elevation and weakly selected ski-pistes at a lower elevation (where the hydroseeded grass cover was high).

Conservation considerations

This study has shown that ski-piste construction causes long-lasting damage to soil, vegetation and ground-dwelling arthropods in high altitude alpine ecosystems. This fact is of particular

conservation concern because several thousands of kilometers of ski-pistes exist in the Alps and the number is still increasing. Moreover, in order to accommodate climate change effects, in the future ski-pistes could be constructed at higher altitudes, where ecosystems are even more fragile and vulnerable. Restoration of ski-pistes by hydroseeding using commercial seed mixtures cannot be considered a *panacea* because it has shown good results but only below a certain altitudinal threshold (about 2500 m a.s.l. in the present study area). Moreover, when revegetation is successful, the seeded plant species are native but are different from those growing in the surrounding alpine vegetation. The seeded plant community is mainly made of grasses and is characterized by a simpler structure than that of the undisturbed one. Despite these limitations, hydroseeding might be useful, apart from the effects of controlling erosion and reducing visual impacts, for the conservation of certain groups of ground-dwelling arthropods, such as grasshoppers and, to a lesser extent, ground beetles. The precise reason why restored ski-pistes are used by these arthropods remains unknown but ski-pistes may be used as oviposition sites or safe havens from predators. The high densities of grasshoppers and, to a lesser extent, ground beetles found in the examined sites suggest that ski-pistes may be used as foraging or hunting sites. This may be good news for several alpine ski-resort areas where species of conservation interest occur. In the Gressoney valley, for example, at least one grasshopper and seven ground beetle species deserve protection because they are endemic to the Alps. IndVal analyses have shown that two of these species were helped by hydroseeding: *Anonconotus alpinus* (a grasshopper) and *Carabus concolor* (a ground beetle) have positively selected restored ski-pistes. Another grasshopper, *Aeropus sibiricus*, a global species with a European distribution restricted to mountains, has also positively selected restored ski-pistes.

It should be underlined that a few species used the ski-pistes independently from restoration interventions. This is the case of the macropterous carabid *Amara quenseli* and, paradoxically (because it is an exception to the rule) by the spider *Coelotes pickardi*, a subspecies that is endemic to the western part of the alpine chain.

References

Abegg B, Koenig U, Buerki R, Elsasser H (1997) Climate impact assessment im tourismus. Die Erde 128:105–116

Amacher-Hoppler A, Schoch R (2008) Remontées Mécaniques Suisses: Faits et Chiffres. Remontées mécaniques Suisse, Berne

Andow DA (1990) Population dynamics of an insect herbivore in simple and diverse habitats. Ecology 71:1006-1017

Arlettaz R, Patthey P, Baltic M, Leu T, Schaub M, Palme R, Jenni-Eiermann S (2007) Spreading free-riding snow sports represent a novel serious threat for wildlife. P Roy Soc B-Biol Sci 274:1219-1224

Audisio P, Vigna Taglianti A (2004) Fauna Europaea: Coleoptera, Carabidae. Fauna Europaea Version 1.1. [WWW document]. URL http://www.faunaeur.org

Barni E, Freppaz M, Siniscalco C (2007) Interactions between vegetation, roots, and soil stability in restored high- altitude ski runs in the Alps. Arct Antarct Alp Res 39:25–33

Bicknell S, McManus P (2006) The canary in the coalmine: Australian ski resorts and their responses to climate change. Geogr Res 44:386-400

Blumer P, Diemer M (1996) The occurrence and consequences of grasshopper herbivory in an Alpine grassland, Swiss Central Alps. Arctic Alpine Res 28:435–440

Brandmayr P, Zetto T, Pizzolotto R, Casale A, Vigna Taglianti A (2005) I Coleotteri Carabidi per la valutazione ambientale e la conservazione della biodiversità. Manuale operativo, APAT, Roma, pp 34

Bremner JM (1965) Inorganic forms of nitrogen. In: Black CA (ed) Methods of soil analysis, Part 2. American Society of Agronomy, Madison, Wisconsin, pp 1179-1206

Brose U (2003) Bottom-up control of carabid beetle communities in early successional wetlands: mediated by vegetation structure or plant diversity. Oecologia 135:407-413

Burt JW (2012) Developing restoration planting mixes for active slopes: a multi-site reference community approach. Environ Manage 49:636-648

Burt JW, Rice KJ (2009) Not all ski slopes are created equal: disturbance intensity affects ecosystem properties. Ecol Appl 19:2242–2253

Caprio E, Chamberlain DE, Isaia M, Rolando A (2011) Landscape changes caused by high altitude ski-pistes affect bird species richness and distribution in the Alps. Biol Conserv 144:2958-2967

Clarke RD, Grant PR (1968) An experimental study of the role of spiders as predators in a forest litter community. Ecology 49:152–154

Crooke WM, Simpson WE (1971) Determination of NH4+ in Kjeldahl Digests of Crops by an Automated procedure. J Sci Food Agr 22:9-10

Delarze R (1994) Vegetation dynamics on the artificially sown ski runs of Crans-Montana (Valais, Suisse). Effets de l'altitude. Bot Helv 104:3–16

Delarze R, Gonseth Y (2008) Guide des Milieux Naturels de Suisse. Rossolis, Lausanne

den Boer PJ (1970) On the significance of dispersal power for populations of Carabid-Beetles (Coleoptera, Carabidae). Oecologia 4:1-28

Dobson AJ (1990) An introduction to generalized linear models. Chapman and Hall, New York

Dufrêne M, Legendre P (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol Monogr 67:345–366

EEA (2010) Europe's Ecological Backbone: Recognising the True Value of our Mountains. EEA Report 6/2010. European Environment Agency, Copenhagen

Elsasser H, Messerli P (2001) The vulnerability of the snow industry in the Swiss Alps. Mt Res Dev 21:335–339

Fielding DJ, Brusven MA (1993) Grasshopper (Orthoptera: Acrididae) community composition and ecological disturbance on southern Idaho rangeland. Environ Entomol 22:71-81

Fontana P, La Greca M, Kleukers R (2005) Ortotteri. Checklist e distribuzione della fauna italiana. In: Roffo S, Stock F (eds) Memorie del Museo Civico di Storia Naturale di Verona—2. Serie. Sezione Scienze della Vita 16, pp 135–136

Fournier DA, Skaug HJ, Ancheta J, Ianelli J, Magnusson A, Maunder MN, Nielsen A, Sibert J (2012) AD model builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim Method Softw 27:233–249

Freppaz M, Lunardi S, Bonifacio E, Scalenghe R, Zanini E (2002) Ski slopes and stability of soil aggregates. In: Pagliai M, Jones R (eds) Sustainable Land Management-Environmental Protection. Catena Verlag, Reiskirchen, Germany, pp 125-132

Fukushima T, Kureha M, Ozaki N, Fujimori Y, Harasawa H (2002) Influences of air temperature change on leisure industries: case study on ski activities. Mitig Adapt Strat Gl 7:173-189

Gros R, Monrozier LJ, Bartoli F, Chotte JL, Faivre P (2004) Relationships between soil physico-chemical properties and microbial activity along a restoration chronosequence of alpine grasslands following ski run construction. Appl Soil Ecol 27:7–22

Haddad NM, Tilman D, Haarstad J, Ritchie M, Knops JMH (2001) Contrasting effects of plant richness and composition on insect communities: a field experiment. Am Nat 158:17–35

Hance T (1990) Relationship between crop types, ground beetle phenology and aphid predation in agroecosystems. In: Stork NE (ed) The role of ground beetles in ecological and environmental studies. Intercept, Andover

Haslett JR (1988) Assessing the quality of alpine habitats: Hoverflies (Diptera: Syrphidae) as bio-indicators of skiing pressure on alpine meadows in Austria. Zool Anz 220:179-184

Hill MO, Gauch HG Jr (1980) Detrended Correspondence Analysis: an improved ordination technique. Vegetatio 42:47–58

Hothorn T, Bretz F, Westfall P (2008) Simultaneous Inference in General Parametric Models. Biometrical J 50:346-363

Illich IP, Haslett JR (1994) Responses of assemblages of Orthoptera to management and use of ski slopes on upper sub-alpine meadows in the Austrian Alps. Oecologia 97:470-474

Isselin-Nondedeu F, Bédécarrats A (2007) Influence of alpine plants growing on steep slopes on sediment trapping and transport by runoff. Catena 71:330–339

Joern A (1982) Vegetation structure and microhabitat selection in grasshoppers (Orthoptera, Acrididae). Southwest Nat 27:197-209

Joern A (2005) Disturbance by fire frequency and bison grazing modulate grasshopper assemblages in tallgrass prairie. Ecology 86:861-873

Kemp WP, Harvey SJ, O'Neill KM (1990) Patterns of vegetation and grasshopper community composition. Oecologia 83:299-308

Kessler T, Cierjacks A, Ernst R, Dziock F (2012) Direct and indirect effects of ski run management on alpine Orthoptera. Biodivers Conserv 21:281-296

Klug B, Markart G, Meier J, Krautzer B, Kohl B, (2013) Ski run re-vegetation: a never-ending story of trial and error? In: Rixen C, Rolando A (eds) The Impacts of Skiing and Related Winter Recreational Activities on Mountain Environments. Bentham Ebooks

Koivula MJ (2011) Useful model organisms, indicators, or both? Ground beetles (Coleoptera, Carabidae) reflecting environmental conditions. ZooKeys 100:287–317

Koleff P, Gaston KJ, Lennon JJ (2003) Measuring beta diversity for presence-absence data. J Anim Ecol 72:367–382

Kopeszki H, Trockner V (1994) Effects of skiing on the collembolan fauna of an alpine meadow in Grodental (south Tyrol). Zool Anz 233:221-239

Koricheva J, Mulder CPH, Schmid B,·Joshi J, Huss-Danell K (2000) Numerical responses of different trophic groups of invertebrates to manipulations of plant diversity in grasslands. Oecologia 125:271-282

Körner C (1999) Alpine Plant Life: Functional Plant Ecology of High Mountain Ecosystems. Springer Verlag, Berlin, Germany

Krautzer B, Wittmann H, Peratoner G, Graiss W, Partl C, Parente G, Venerus S, Rixen C, Streit M (2006) Site-specific high zone restoration in the Alpine region, the current technological development. Federal Research and Education Centre (HBLFA) Raumberg-Gumpenstein Irdning, no. 46, pp 135

Krautzer B, Graiss W, Klug B (2013) Ecological restoration of ski runs. In: Rixen C, Rolando A (eds) The Impacts of Skiing and Related Winter Recreational Activities on Mountain Environments. Bentham Ebooks

Kromp B (1999) Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. Agr Ecosyst Environ 74:187-228

Kruess A, Tscharntke T (2002) Contrasting responses of plant and insect diversity to variation in grazing intensity. Biol Conserv 106:293-302

Kyto M, Niemela P, Larsson S (1996) Insects on trees: population and individual response to fertilization. Oikos 75:148-159

LaGrange A, Le Roux N, Gardner-Lubbe S (2009) BiplotGUI: Interactive biplots in R. J Stat Softw 30:1-37

Laiolo P, Rolando A (2005) Forest bird diversity and ski-runs: A case of negative edge effect. Anim Conserv 8:9-16

Laiolo P, Dondero F, Ciliento E, Rolando A (2004) Consequences of pastoral abandonment for the structure and diversity of the alpine avifauna. J Appl Ecol 41:294–304

Legendre P, Legendre L (1998) Numerical ecology, 2nd English edn. Elsevier Science B.V, Amsterdam, The Netherlands

Lövei GL, Sunderland KD (1996) Ecology and behavior of ground beetles (Coleoptera: Carabidae). Annu Rev Entomol 41:231–256

Martin C, Pohl M, Alewell C, Körner C, Rixen C (2010) Interrill erosion at disturbed alpine sites: Effects of plant functional diversity and vegetation cover. Basic Appl Ecol 11:619-626

Mennella C (1972) Il clima d'Italia nelle sue caratteristiche e varietà e quale fattore dinamico del paesaggio. Vol. II, Fratelli Conte Editore SPA, Napoli

Mosimann T (1985) Geo-ecological impacts of ski piste construction in the SwissAlps. Appl Geogr 5:29–37

Negro M, Isaia M, Palestrini C, Rolando A (2009) The impact of forest ski-pistes on diversity of ground-dwelling arthropods and small mammals in the Alps. Biodivers Conserv 18:2799-2821

Negro M, Isaia M, Palestrini C, Schoenhofer A, Rolando A (2010) The impact of high-altitude ski pistes on ground-dwelling arthropods in the Alps. Biodivers Conserv 19:1853-1870

Negro M, Novara C, Bertolino S, Rolando A (2013) Ski pistes are ecological barriers to forest small mammals. Eur J Wildlife Res 59:57–67

Niemelä J, Koivula M, Kotze DJ (2007) The effects of forestry on carabid beetles (Coleoptera: Carabidae) in boreal forests. J Insect Conserv 11:5–18

Oksanen J, Kindt R, O'Hara RB (2005) Vegan: Community Ecology. Package version 1.6-10. <http://cc.oulu.fi/   jarioksa/>

Paschetta M, La Morgia V, Masante D, Negro M, Rolando A, Isaia M (2012). Grazing history influences biodiversity: a case study on ground-dwelling arachnids (Arachnida: Araneae, Opiliones) in the Natural Park of Alpi Marittime (NW Italy). J Insect Conserv DOI 10.1007/s10841-012-9515-y

Patthey P, Wirthner S, Signorell N, Arlettaz R (2008) Impact of outdoor winter sports on the abundance of a key indicator species of alpine ecosystems. J Appl Ecol 45:1704–1711

Pauli H, Gottfried M, Reiter K, Klettner C, Grabherr G (2007) Signals and range expansions and contractions of vascular plants in the high Alps: observations (1994–2004) at the GLORIA master site Schrankogel, Tyrol, Austria. Glob Change Biol 13:147-156

Pearce Jl, Venier LA, Eccles G, Pedlar J, Mckenney D (2004) Influence of habitat and microhabitat on epigeal spider (Araneae) assemblages in four Stand types. Biodivers Conserv 13:1305–1334

Perner J, Wytrykush C, Kahmen A, Buchmann N, Egerer I, Creutzburg S, Odat N, Audorff V, Weisser WW (2005) Effects of plant diversity, plant productivity and habitat parameters on arthropod abundance in montane European grasslands. Ecography 28:429–442

Pintar M, Mali B, Kraigher H (2009) The impact of ski slopes management on Krvavec ski resort (Slovenia) on hydrological functions of soils. Biologia 64:639–642

Platnick NI (2013) The world spider catalog, version 13.5. American Museum of Natural History, online at http://research.amnh.org/iz/spiders/catalog. DOI: 10.5531/db.iz.0001

Pohl M, Alig D, Körner C, Rixen C (2009) Higher plant diversity enhances soil stability in disturbed alpine ecosystems. Plant Soil 324:91–102

Raes M, De Troch M, Ndaro SGM, Muthumbi A, Guilini K, Vanreusel A (2007) The structuring role of microhabitat type in coral degradation zones: a case study of nematodes from Kenya and Zanzibar. J Coral Reef Res 26:113–126

R Development Core Team (2012) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. ISBN 3-900051-07-0. http://www.R-project.org/

Risch SJ, Andow D, Altieri MA (1983) Agroecosystem diversity and pest control: data, tentative conclusions, and new research directions. Environ Entomol 12:625–629

Roberts DW (2010) labdsv: ordination and multivariate analysis for ecology. R package version 1.4-1. R Foundation for Statistical Computing, Vienna, Austria. http://cran.r-project.org/web/packages/labdsv/labdsv.pdf

Rolando A, Caprio E, Rinaldi E, Ellena I (2007) The impact of high-altitude ski-runs on alpine grassland bird communities. J Appl Ecol 44:210–219

Rolando A, Laiolo P (1997) A comparative analysis of the diet of the Chough (Pyrrhocorax pyrrhocorax) and the Alpine Chough (P. graculus) co-existing in the Alps. Ibis 139:388–395

Rolando A., Negro M., Passerin D'Entrèves P., Balletto E., Palestrini C. (2013) The effect of forest ski-pistes on butterfly assemblages in the Alps. Insect Conserv Diver 3:212–222

Rolando A, Patterson IJ (1993) Foraging behaviour and diet of the Alpine chough Pyrrhocorax graculus in relation to human developments in the Italian Alps in summer. J Ornithol 134:181–187

Roux-Fouillet P, Wipf S, Rixen C (2011) Long-term impacts of ski piste management on alpine vegetation and soils. J Appl Ecol 48:906–915

Samu F, Sunderland KD, Szinetár C (1999) Scale-dependent dispersal and distribution patterns of spiders in agricultural systems: a review. J Arachnol 27:325–332

Schaffers AP, Raemakers IP, Sykora KV, Ter Braak CJF (2008) Arthropod assemblages are best predicted by plant species composition. Ecology 89:782–794

Scott D, Dawson J, Jones B (2008) Climate change vulnerability of the US Northeast winter recreation – tourism sector. Mitig Adapt Strat Gl 13:577-596

Scrucca L (2004) qcc: an R package for quality control charting and statistical process control. R News 4:11–17

Soil Survey Staff (2010) Keys to Soil Taxonomy, 11th ed. USDA-Natural Resources Conservation Service, Washington, DC

Thiel D, Menoni E, Brenot JF, Jenni L (2007) Effects of recreation and hunting on flushing distance of Capercaillie. J Wildlife Manage 71:1784–1792

Torrusio S, Cigliano MM, De Wysiecki ML (2002) Grasshopper (Orthoptera: Acridoidea) and plant community relationships in the Argentine pampas. J Biogeogr 29:221-229

Urbanska KM, Fattorini M (2000) Seed rain in high-altitude restoration plots in Switzerland. Restor Ecol 8:74-79

van den Berghe EP (1992) On pitfall trapping invertebrates. Entomol News 103:149–158

Van Ommeren RJ (2001) Species composition on reclaimed ski runs compared with unseeded areas. J Range Manage 54:307–311

Wachter DH, O'Neill KM, Kemp WP (1998) Grasshopper (Orthoptera: Acrididae) communities on an elevational gradient in southwestern Montana. J Kansas Entomol Soc 71:35–43

Wheeler B (2010) lmPerm: Permutation tests for linear models. R package version 1.1-2

Wilson RJ, Gutiérrez D, Gutiérrez J, Martinez D, Agudo R, Monserrat VJ (2005) Changes to the elevational limits and extent of species ranges associated with climate change. Ecol Lett 8:1138-1146

Wipf S, Rixen C, Fischer M, Schmid B, Stoeckli V (2005) Effects of ski piste preparation on alpine vegetation. J Appl Ecol 42:306–316

Zuur AF, Ieno EN, Walker N, Saveliev AA, Smith GM (2009) Mixed effects models and extensions in ecology with R. Springer, pp 574
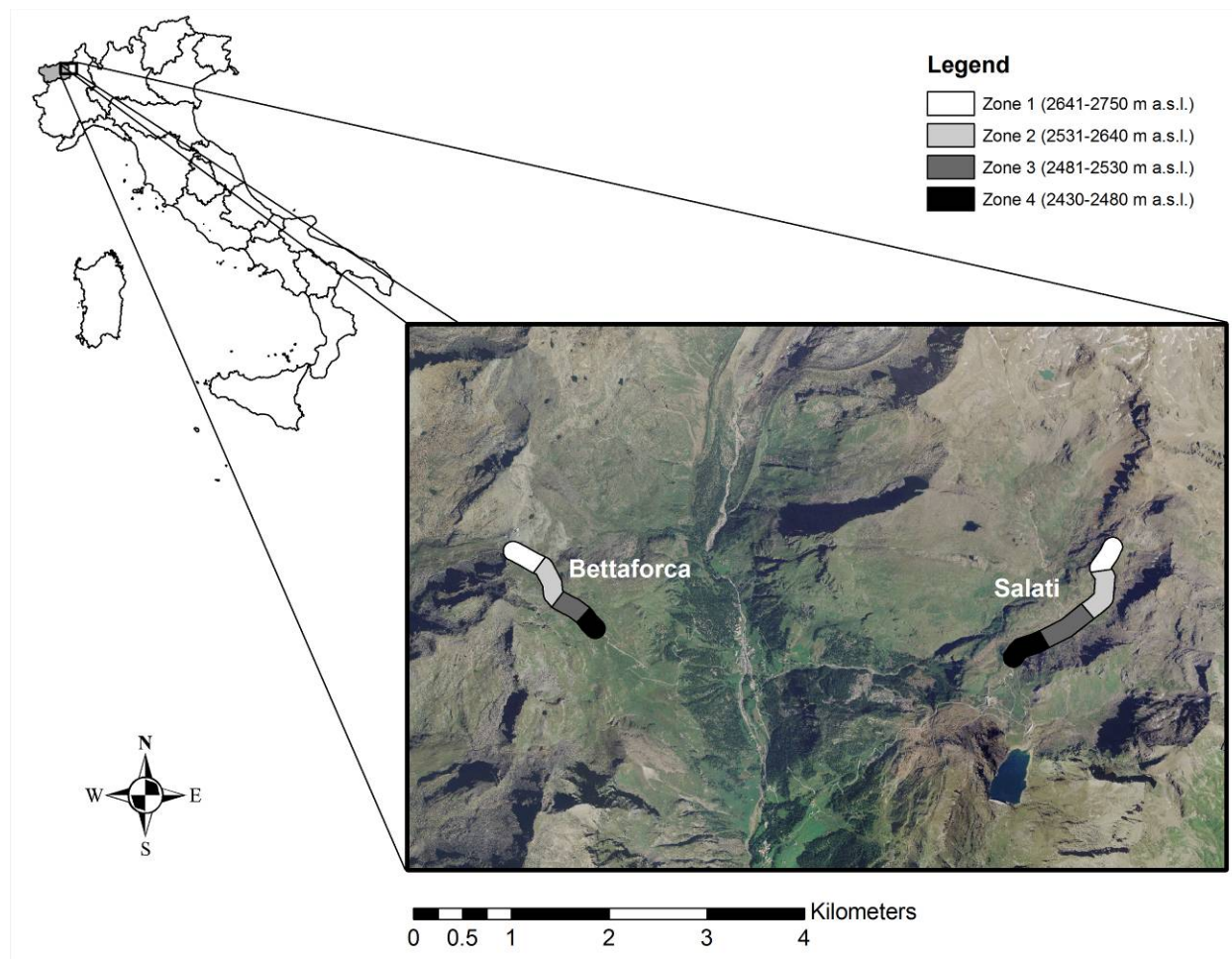
Fig.1: Map of the study area in the Gressoney-La-Trinité ski resort (Aosta Valley region, NW-Italian Alps). The four altitudinal zones, into which the ski-pistes of the two sites (Bettaforca and Salati) have been subdivided, are shown in different colors. One main ski-piste and several lateral ones have been studied in both sampling sites.
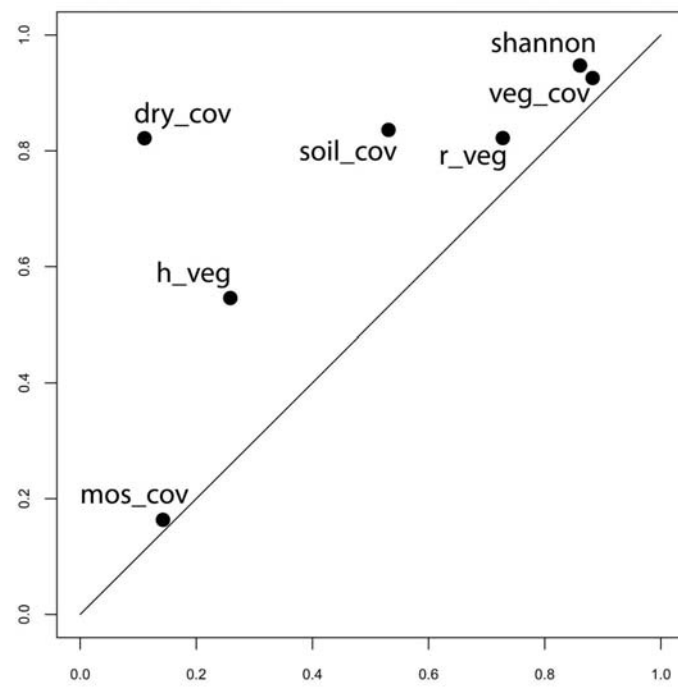
Fig.2: Axis predictivities diagram. The further to the right a vegetation variable appears, the better it is represented in the first (or horizontal) biplot dimension (PC1). The closer to the top of the diagram, the better the variable is represented overall in the biplot, taking into account the contribution of both the first and the second biplot dimensions (PC1 + PC2). The marginal contribution of the second principal component is indicated by the vertical distance between the diagonal line and the variable (LaGrange et al., 2009).

h_veg: height of vegetation; r_veg: number of species; shannon: Shannon plant diversity; veg_cov: vegetation cover; mos_cov: moss cover; soil_cov: bare ground cover.
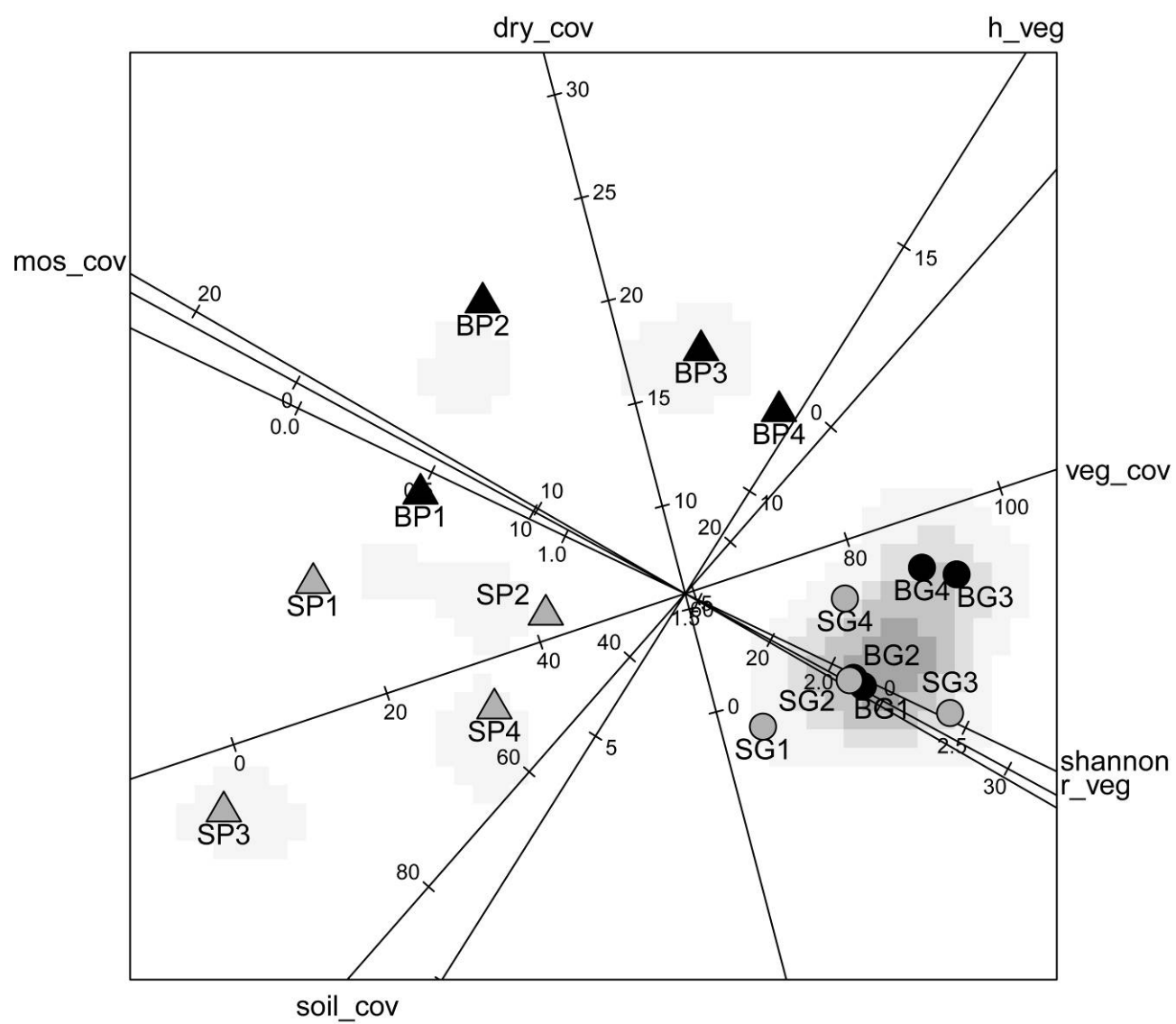
Fig.3: PCA bi-plots constructed using the vegetation variables. Variable labels indicate the direction of the vectors and the original variable values are shown along each vector.
Each symbol indicates the mean value (centroid) of three vegetation subplots and the label is a code that identifies the site (B=Bettaforca; S=Salati), habitat type (P=ski-piste; G=natural grassland) and zone (1, 2, 3 and 4). To facilitate the reading of the chart, the black circle indicates Bettaforca natural grassland, grey circle Salati natural grassland, black triangle Bettaforca ski-piste and grey triangle Salati ski-piste. Shaded areas indicate the density of individual vegetation surveys (higher with darker colours) underlying the vectors.

h_veg: height of vegetation; r_veg: number of species; shannon: Shannon plant diversity; veg_cov: vegetation cover; mos_cov: moss cover; soil_cov: bare ground cover; dry_cov: dry matter cover.
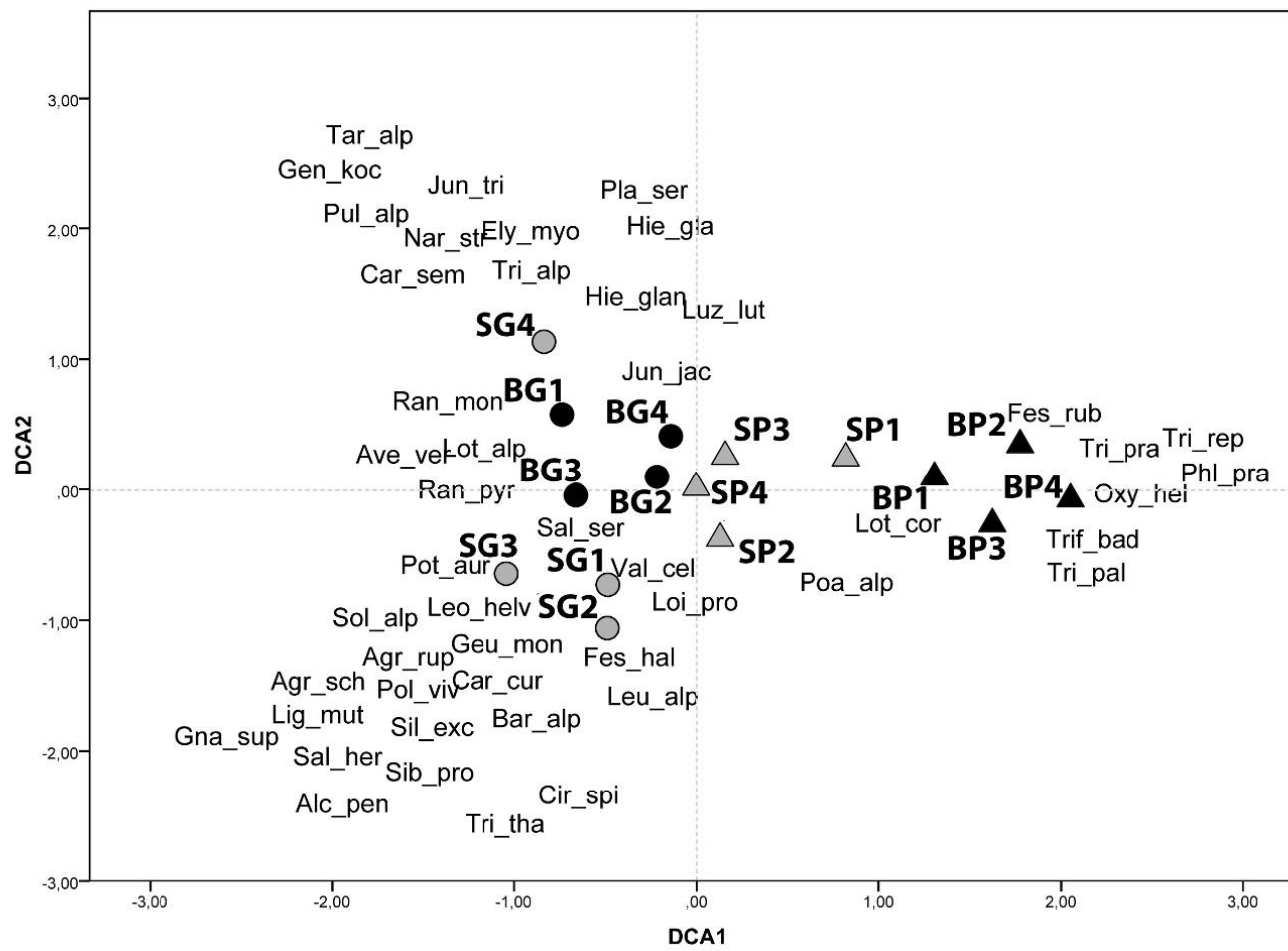
Fig.4: Plant species and vegetation survey scores in the space defined by axes 1 and 2 of DCA based on the percentage cover values of the occurring species. The eigenvalues of axis 1 and 2 were 0.71 and 0.42 respectively. The name of the species uses the first three letters of the genus and the first three letters of the specific epithet (see also appendix 1). Each symbol indicates the mean value (centroid) for the three vegetation subplots and the label is a code that identifies site (B=Bettaforca; S=Salati), habitat type (P=ski-piste; G=natural grassland) and zone (1, 2, 3 and 4). To facilitate the reading of the chart, the black circle indicates Bettaforca natural grassland, grey circle Salati natural grassland, black triangle Bettaforca ski-piste and grey triangle Salati ski-piste.
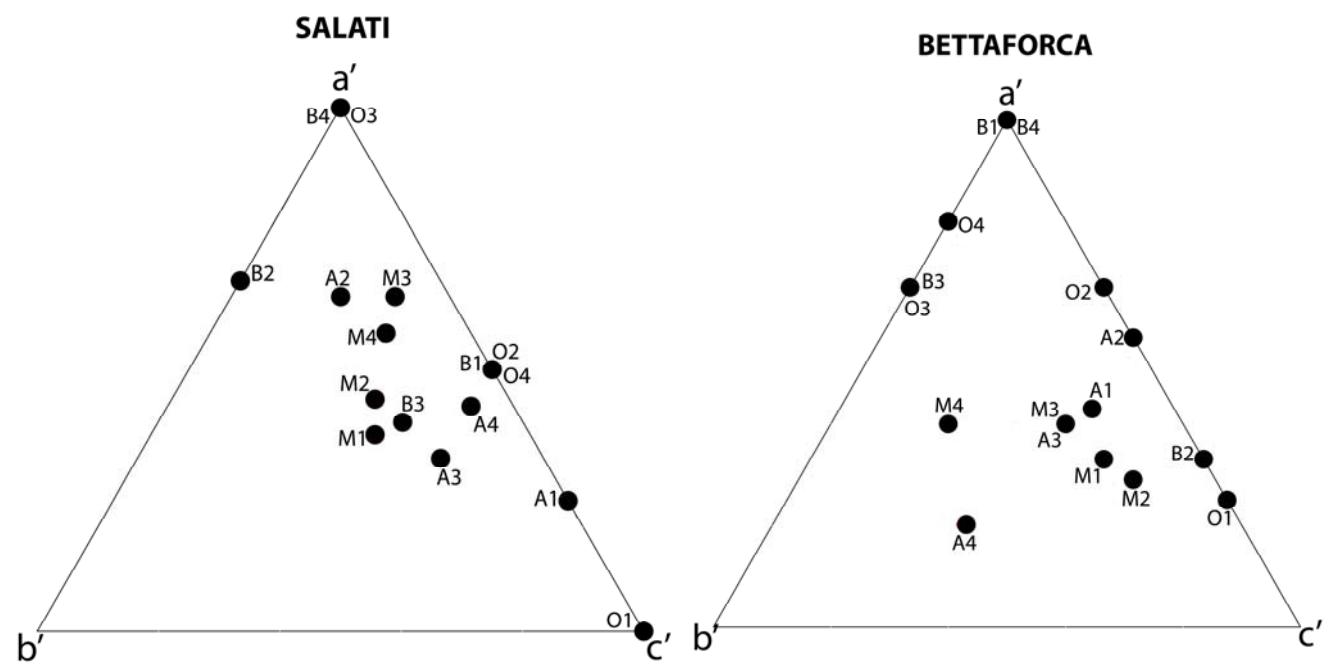
Fig.5: Salati and Bettaforca ternary plots representing species overlap between pairs of habitats (natural grassland *vs.* ski-piste). The triangle vertices are as follows: a' is the percentage of species that are present in both habitats, b' is the percentage of species that are present only in the neighboring habitat (ski-piste), while c' is the percentage of species present only in the focal habitat (natural grassland). The point label is a code that identifies arthropod group (M= Macropterous Carabid, B=Brachypterous Carabid, A=Araneae, O=Orthoptera) and zone (1, 2, 3 and 4).

	Zone	SALATI Abundance (N) Estimate	S.E.	p	Species richness (R) Estimate	S.E.	p	BETTAFORCA Abundance (N) Estimate	S.E.	p	Species richness (R) Estimate	S.E.	p
Brachypterous carabids (BRA)	1	-1.15	0.32	**<0.001**	too few data			-0.67	0.33	**<0.05**	-0.38	0.34	0.25
	2	-1.44	0.22	**<0.001**	-0.46	0.23	**<0.05**	-1.32	0.31	**<0.001**	-0.57	0.31	0.06
	3	-0.91	0.15	**<0.001**	-0.35	0.19	0.07	-0.77	0.32	**<0.05**	-0.06	0.26	0.82
	4	-0.76	0.20	**<0.001**	-0.33	0.18	0.07	0.02	0.28	0.94	0.3	0.31	0.33
Macropterous carabids (MAC)	1	-0.27	0.68	0.70	-0.26	0.58	0.66	-1.96	0.50	**<0.001**	-1.33	0.45	**<0.01**
	2	-0.57	0.33	0.08	-0.22	0.26	0.41	-1.15	0.32	**<0.001**	-0.86	0.33	**<0.01**
	3	0.17	0.31	0.59	0.07	0.28	0.79	-0.11	0.25	0.68	0.01	0.29	0.98
	4	0.53	0.33	0.11	0.22	0.31	0.48	0.01	0.36	0.98	-0.25	0.32	0.44
Orthoptera (ORT)	1	too few data			too few data			-1.78	0.68	**<0.01**	-1.47	0.64	**<0.05**
	2	-0.76	0.62	0.22	-0.50	0.62	0.41	-1.80	0.61	**<0.01**	-1.62	0.63	**<0.01**
	3	-0.87	0.47	0.06	-0.64	0.36	0.07	1.14	0.37	**<0.01**	0.68	0.30	**<0.05**
	4	-1.84	0.48	**<0.001**	-1.05	0.39	**<0.01**	1.20	0.33	**<0.001**	0.42	0.26	**0.09**
Araneae (ARA)	1	-1.50	0.60	**<0.05**	-1.74	0.73	**<0.05**	-0.65	0.35	**0.06**	-0.88	0.38	**<0.05**
	2	-1.18	0.32	**<0.001**	-0.66	0.25	**<0.01**	-1.40	0.33	**<0.001**	-1.00	0.36	**<0.01**
	3	-1.10	0.25	**<0.001**	-0.78	0.20	**<0.001**	-1.04	0.36	**<0.001**	-0.67	0.28	**<0.05**
	4	-0.75	0.26	**<0.01**	-0.73	0.23	**<0.01**	-1.49	0.31	**<0.001**	-1.01	0.30	**<0.001**

Table 1: Differences between the natural grassland (set as the reference category) and ski-piste. Habitat factor estimates and statistical significance (GLMMs) for abundance and species richness, in relation to sampling site (Salati and Bettaforca) and four altitudinal zones, are shown in the table. Significant comparisons are in bold type.
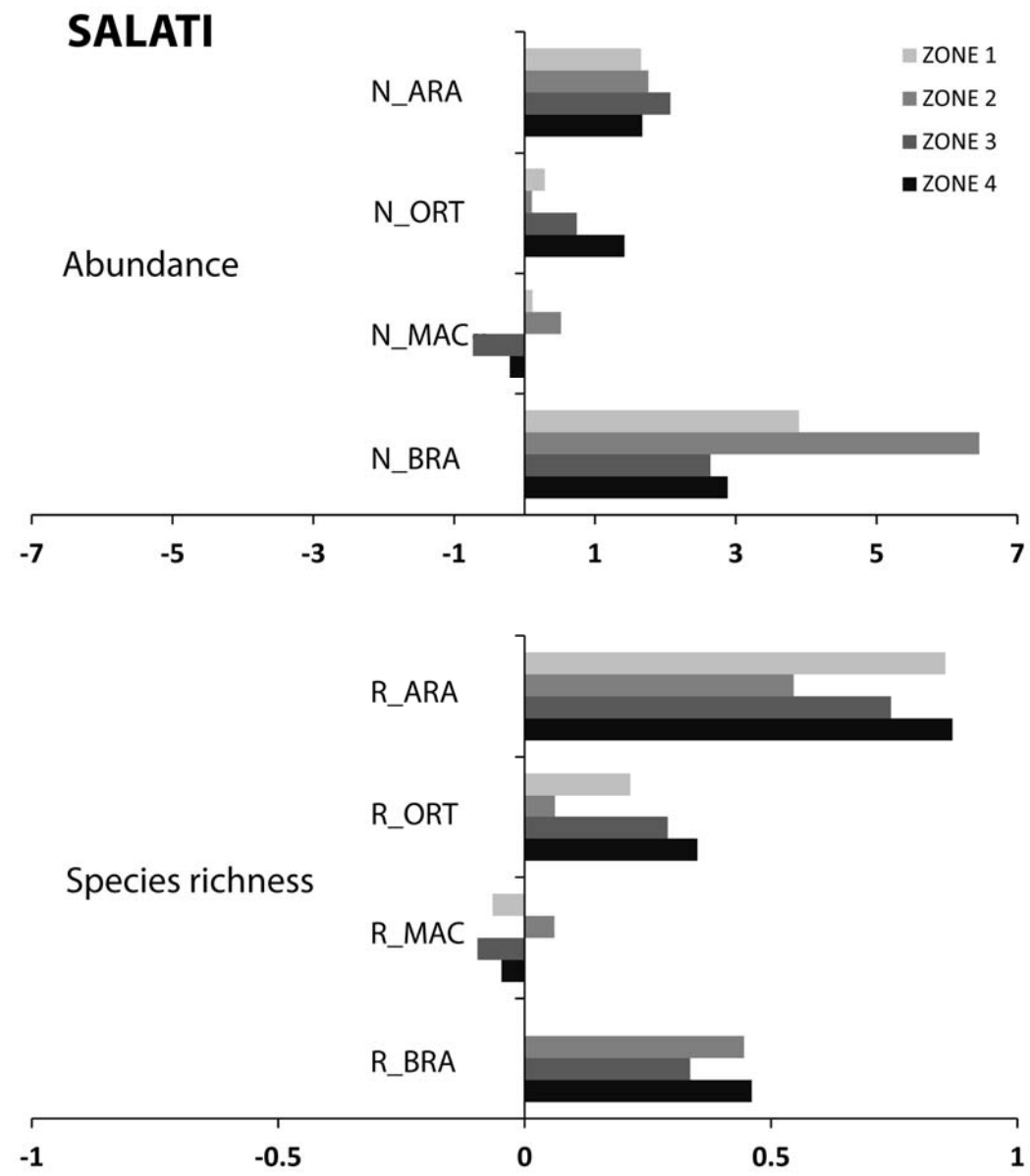
Fig.6: Differences in mean abundance and mean species richness between the natural grassland and ski-piste in the Salati site. The label is a code that identifies the diversity parameter (N=abundance, R=species richness) and arthropod group (ARA=Araneae, ORT=Orthoptera, MAC=Macropterous Carabid, BRA=Brachypterous Carabid).
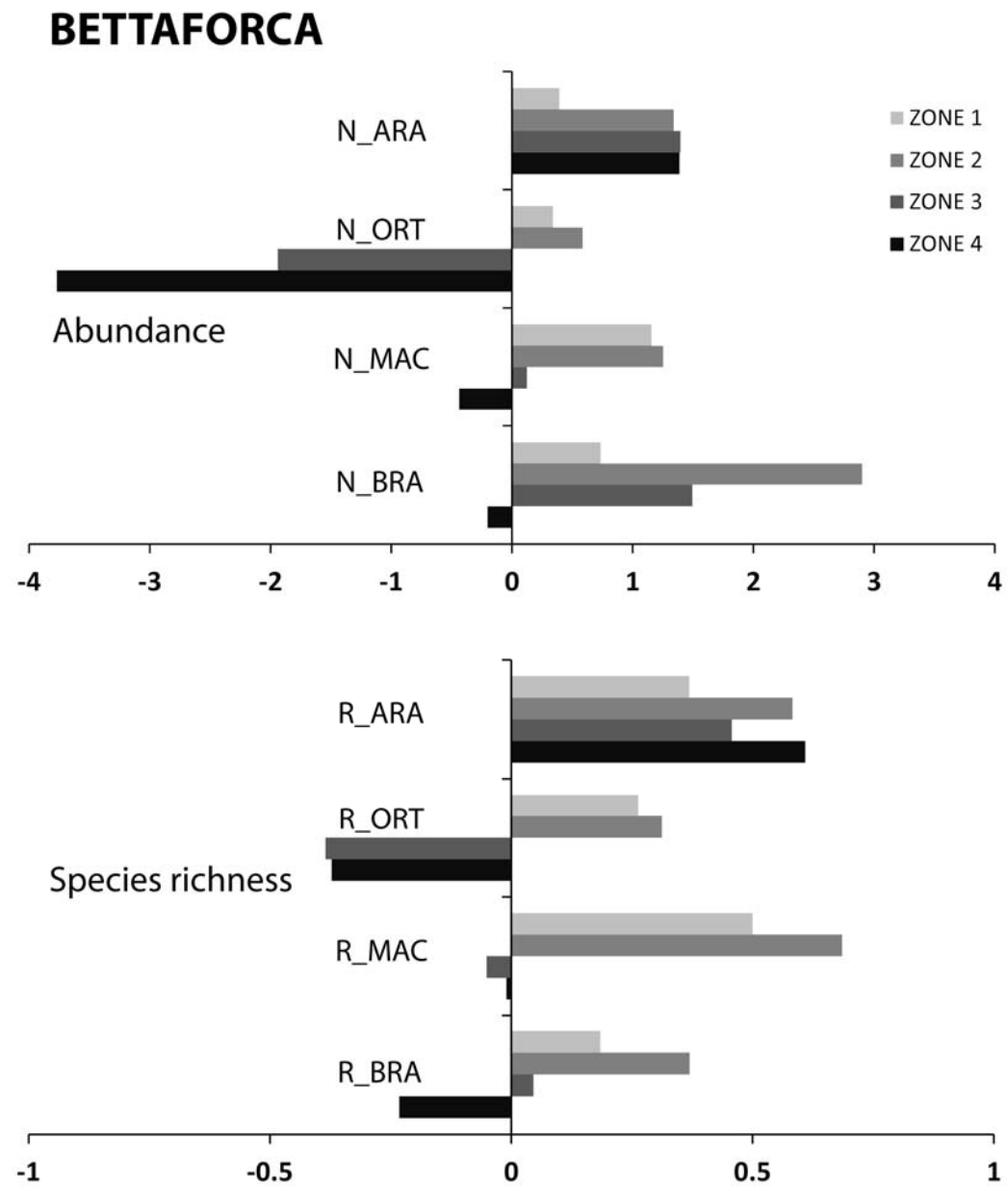
Fig.7: Differences in mean abundance and mean species richness between the natural grassland and ski-piste in the Bettaforca site. The label is a code that identifies the diversity parameter (N=abundance, R=species richness) and arthropod group (ARA=Araneae, ORT=Orthoptera, MAC=Macropterous Carabid, BRA=Brachypterous Carabid).

| Zone	SALATI Species	Habitat	IV	p	BETTAFORCA Species	Habitat	IV	p
	Brachypterous carabids				Macropterous carabids			
	Carabus concolor	natural grassland	0.70	<0.01	*Cymindis vaporariorum*	natural grassland	0.37	<0.001
					Araneae			
Zone 1					*Xysticus desidiosus*	natural grassland	0.16	<0.05
	Brachypterous carabids				Brachypterous carabids			
	Carabus concolor	natural grassland	0.76	<0.001	*Carabus concolor*	natural grassland	0.58	<0.01
	Pterostichus cribratus	natural grassland	0.21	<0.05	Macropterous carabids			
	Macropterous carabids				*Cymindis vaporariorum*	natural grassland	0.39	<0.001
	Cymindis vaporariorum	natural grassland	0.40	<0.001	*Amara quenseli*	ski-piste	0.11	<0.05
	Ocydromus incognitus	ski-piste	0.23	<0.001	Araneae			
	Araneae				*Pardosa mixta*	natural grassland	0.44	<0.001
	Drassodes cupreus	natural grassland	0.19	<0.05	Orthoptera			
Zone 2	*Pardosa mixta*	natural grassland	0.20	<0.05	*Aeropus sibiricus*	natural grassland	0.20	<0.05
	Brachypterous carabids				Brachypterous carabids			
	Carabus concolor	natural grassland	0.61	<0.001	*Pterostichus cribratus*	natural grassland	0.39	<0.01
	Pterostichus cribratus	natural grassland	0.14	<0.01	Araneae			
	Macropterous carabids				*Coelotes pickardi*	natural grassland	0.11	<0.05
	Cymindis vaporariorum	natural grassland	0.18	<0.001	*Pardosa mixta*	natural grassland	0.41	<0.05
	Ocydromus incognitus	ski-piste	0.19	<0.01	Orthoptera			
	Araneae				*Anonconotus alpinus*	ski-piste	0.17	<0.05
	Haplodrassus signifer	natural grassland	0.32	<0.001				
	Meioneta alpica	natural grassland	0.13	<0.01				
Zone 3	*Pardosa mixta*	natural grassland	0.17	<0.01				
	Brachypterous carabids				Brachypterous carabids			
	Carabus latreinneanus	natural grassland	0.31	<0.05	*Carabus concolor*	ski-piste	0.38	<0.05
	Pterostichus cribratus	natural grassland	0.35	<0.01	Araneae			
	Macropterous carabids				*Pardosa mixta*	natural grassland	0.44	<0.01
	Amara quenseli	ski-piste	0.28	<0.001	*Xysticus desidiosus*	natural grassland	0.19	<0.01
	Araneae				Orthoptera			
	Haplodrassus signifer	natural grassland	0.20	<0.05	*Aeropus sibiricus*	ski-piste	0.45	<0.05
	Pardosa mixta	natural grassland	0.22	<0.01	*Anonconotus alpinus*	ski-piste	0.34	<0.01
	Pardosa blanda	natural grassland	0.24	<0.01				
	Coelotes pickardi	ski-piste	0.22	<0.01				
	Orthoptera							
Zone 4	*Aeropus sibiricus*	natural grassland	0.30	<0.05				

Table 2: Indicator species analysis (IndVal). Species that significantly indicate one of the two habitat types (natural grassland or ski-piste) are shown. Maximum observed indicator value and *p*-value, obtained by Monte Carlo randomization tests (1,000 runs), are given.

	SALATI								BETTAFORCA							
	SG1	SP1	SG2	SP2	SG3	SP3	SG4	SP4	BG1	BP1	BG2	BP2	BG3	BP3	BG4	BP4
Achillea moschata Wulfen								■								
Achillea nana L.									■	■	■		■			
Agrostis rupestris All.	■		■	■									■			
Agrostis schraderana Becherer	■		■													
Alchemilla vulgaris L. gr			■	■											■	
Alchemilla pentaphyllea L.			■	■					■							
Androsace obtusifolia All.					■						■					
Antennaria carpathica (Wahlenb.) Bl. Et Fing.									■							
Anthoxanthum alpinum Loeve Et Loeve							■						■		■	
Armeria alpina Willd.	■						■									
Anthyllis vulneraria L. gr									■							
Arenaria biflora L.				■												
Avenula versicolor (Vill.) Lainz			■						■		■					
Bartsia alpina L.	■								■		■					
Botrychium lunaria (L.) Swartz					■		■									
Bupleurum stellatum L.									■							
Bupleurum ranunculoides L.									■							
Calluna vulgaris (L.) Hull			■													
Campanula barbata L.													■			
Campanula scheuchzeri Vill.					■	■			■							
Cardamine alpina Willd.											■		■			
Cardamine resedifolia L.									■							
Carex curvula All.	■		■						■							
Carex foetida All.					■											
Carex rosae (Gilomen) Hess Et Landolt																
Carex sempervirens Vill.			■				■		■				■			
Cerastium arvense L.						■		■								
Cerastium holosteoides Fries Ampl. Hylander											■			■		
Cerastium cerastioides (L.) Britton		■		■												
Cirsium spinosissimum (L.) Scop.				■	■						■					
Coeloglossum viride (L.) Hartm.	■															
Deschampsia caespitosa (L.) Beauv.				■												
Draba aizoides L.									■							
Draba siliquosa Bieb.											■					
Elyna myosuroides (Vill.) Fritsch	■				■				■							
Epilobium angustifolium L.																
Erigeron uniflorus L.	■									■	■					

	SALATI								BETTAFORCA							
	SG1	SP1	SG2	SP2	SG3	SP3	SG4	SP4	BG1	BP1	BG2	BP2	BG3	BP3	BG4	BP4
Erysimum jugicola Jordan									■							
Euphrasia minima Jacq. Ex Dc.	■		■		■				■		■		■		■	
Festuca rubra L. gr	■	■		■	■				■		■		■		■	
Festuca halleri All.	■		■				■		■		■		■		■	
Festuca varia Haenke							■									
Galium anisophyllum Vill.									■				■			
Gentiana kochiana Perr. Et Song.					■								■			
Gentiana nivalis L.	■															
Gentiana purpurea L.													■			
Gentianella tenella (Rottb.) Borner															■	
Gentiana verna L.									■		■					
Gnaphalium hoppeanum Koch										■		■				
Geum montanum L.	■		■		■		■									
Gnaphalium supinum L.			■	■				■								
Hieracium auricula Lam. Et Dc.															■	
Hieracium glaciale Reyner	■		■	■					■							
Hieracium glanduliferum Hoppe									■		■					
Hieracium pilosella L.																
Homogyne alpina (L.) Cass.			■	■			■		■							
Juncus jacquinii L.	■		■	■	■		■		■		■					
Juncus trifidus L.	■								■		■					
Leontodon helveticus Merat	■		■													
Leucanthemum vulgare Lam.															■	
Leucanthemopsis alpina (L.) Heyw.	■		■		■								■			
Ligusticum mutellinoides (Crantz) Vill.	■		■													
Loiseleuria procumbens (L.) Desv.					■		■									
Lotus alpinus (Dc.) Schleicher					■		■									
Lotus corniculatus L.															■	
Luzula alpino-pilosa (Chaix) Breistr.	■		■		■											
Luzula lutea (All.) Lam. Et Dc.											■		■			
Luzula spicata (L.) Dc.			■	■												
Minuartia sedoides (L.) Hiern													■			
Minuartia verna (L.) Hiern	■			■					■		■					
Myosotis alpestris F.W. Schmidt							■									
Nardus stricta L.																
Nigritella nigra (L.) Rchb. F.															■	
Oxytropis helvetica Scheele	■								■		■				■	

	SALATI								BETTAFORCA							
	SG1	SP1	SG2	SP2	SG3	SP3	SG4	SP4	BG1	BP1	BG2	BP2	BG3	BP3	BG4	BP4
Pedicularis kerneri D.Torre	■															
Phleum alpinum L.				■					■				■			
Phleum pratense L.										■		■				■
Phyteuma globulariifolium Sternb. Et Hoppe	■		■	■					■							
Phyteuma hemisphaericum L.									■		■					
Plantago serpentina All.					■	■									■	■
Poa alpina L.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Polygala alpestris Rchb.																
Polygonum viviparum L.	■								■							
Potentilla aurea L.	■		■						■		■		■			
Potentilla crantzii (Crantz) Beck									■		■					
Rumex scutatus L.								■								
Pulsatilla alpina (L.) Delarbre					■											
Pulsatilla vernalis (L.) Miller									■							
Ranunculus montanus Willd.	■				■		■				■					
Ranunculus pyrenaeus L.					■		■				■		■			
Rhinanthus aristatus Celak.													■			
Sagina apetala Ard.		■														
Sagina glabra (Willd.) Fenzl								■								
Sagina saginoides (L.) Karsten										■			■			
Salix reticulata L.									■							
Salix herbacea L.	■		■						■							
Salix serpillyfolia Scop.					■				■		■					
Saxifraga exarata Vill.											■					
Sempervivum arachnoideum L.									■							
Sempervivum montanum L.	■										■		■			
Sempervivum tectorum L.															■	
Senecio incanus L.	■		■						■							
Senecio halleri Dandy									■							
Sibbaldia procumbens L.			■		■								■			
Silene excapa All.	■		■				■									
Silene acaulis (L.) Jacq.									■	■	■				■	
Silene vulgaris (Moench) Garcke								■								
Silene rupestris L.																
Soldanella alpina L.	■		■				■		■							
Taraxacum alpinum (Hoppe) Hegetschw.					■											
Thlaspi alpestre L.								■								

	SALATI									BETTAFORCA							
	SG1	SP1	SG2	SP2	SG3	SP3	SG4	SP4		BG1	BP1	BG2	BP2	BG3	BP3	BG4	BP4
Thymus polytrichus Kerner										■							
Trifolium alpinum L.			■		■		■			■		■				■	
Trifolium hybridum L.											■		■				
Trifolium pallescens Schreber		■		■		■		■			■			■			■
Trifolium pratense L.					■						■					■	■
Trifolium thalii Vill.	■				■									■			
Trifolium repens L.											■	■					
Trifolium badium Schreber	■			■	■							■				■	
Tussilago farfara L.						■											■
Valeriana celtica L.	■		■							■		■		■			
Vaccinium gaultherioides Bigelow							■										
Veronica alpina L.				■	■		■			■		■				■	
Veronica bellidioides L.			■		■	■					■	■					
Veronica fruticans Jacq.																	
Viola calcarata L.					■					■				■		■	

Appendix 2 List of the collected ground dwelling arthropod species. The label identifies site (S=Salati; B=Bettaforca), habitat type (P=ski-piste; G=natural grassland) and zone (1, 2, 3 and 4). A grey box indicates the presence of the species.

	SALATI								BETTAFORCA							
	SG1	SP1	SG2	SP2	SG3	SP3	SG4	SP4	BG1	BP1	BG2	BP2	BG3	BP3	BG4	BP4
Coleoptera Carabidae																
Amara aulica (Panzer, 1796)																�
Amara erratica (Duftschmid, 1812)	▦	▦														
Amara infuscata (Putzeys, 1866)					▦		▦									
Amara praetermissa (C.R. Sahlberg, 1827)		▦							▦				▦			
Amara quenseli (Schönherr, 1806)	▦	▦		▦												
Calathus melanocephalus (Linné, 1758)																
Calathus micropterus (Duftschmid, 1812)					▦											
Carabus concolor Fabricius, 1792	▦												▦			
Carabus latreilleanus Csiki, 1927	▦												▦			
Cicindela gallica Brullé, 1834				▦		▦										
Cychrus cordicollis Chaudoir, 1835																
Cymindis vaporariorum (Linné, 1758)	▦															
Harpalus rubripes (Duftschmid, 1812)																
Harpalus solitaris Dejean, 1829									▦	▦						
Notiophilus aquaticus (Linné, 1758)			▦													
Notiophilus biguttatus (Fabricius, 1779)						▦					▦	▦				
Ocydromus incognitus (G. Müller, 1931)		▦		▦	▦											
Ocydromus magellensis (Schauberger, 1922)					▦											
Ocydromus rhaeticus (Heer, 1857)	▦															
Oronebria castanea (Bonelli, 1810)	▦															
Oronebria picea (Dejean, 1826)																
Platynus complanatus Dejean, 1828							▦									
Princidium bipunctatum (Linné, 1761)	▦		▦		▦							▦				
Pterostichus cribratus (Dejean, 1828)			▦													
Synuchus vivalis (Illiger, 1798)																
Trichoticnus laevicollis (Duftschmid, 1812)					▦											
Orthoptera																
Podisma pedestris (Linné, 1758)	▦		▦		▦		▦		▦		▦		▦		▦	
Melanoplus frigidus (Boheman, 1846)	▦		▦		▦		▦		▦		▦					
Omocestus viridulus (Linné, 1758)																
Aeropus sibiricus (Linné, 1767)	▦		▦		▦		▦		▦		▦		▦		▦	
Anonconotus alpinus (Yersin, 1858)							▦		▦		▦		▦		▦	
Araneae																
Alopecosa cuneata (Clerck, 1757)											▦					
Asagena phalerata (Panzer, 1801)							▦				▦					
Agroeca proxima (O. P.-Cambridge, 1871)											▦					
Coelotes pickardi O. P.-Cambridge, 1873	▦															
Coelotes rudolfi (Schenkel, 1925)													▦			
Drassodes cupreus (Blackwall, 1834)	▦	▦														
Drassodes lapidosus (Walckenaer, 1802)																
Erigone dentipalpis (Wider, 1834)			▦													
Gnaphosa petrobia L. Koch, 1872	▦															
Gnaphosa badia (L. Koch, 1866)																▦
Haplodrassus signifer (C. L. Koch, 1839)																
Histopona leonardoi Bolzern, Pantini & Isaia, 2013																
Meioneta alpica (Tanasevitch, 2000)	▦		▦													
Mughiphantes handschini (Schenkel, 1919)																
Ozyptila trux (Blackwall, 1846)												▦				
Pardosa bifasciata (C. L. Koch, 1834)							▦									
Pardosa blanda (C. L. Koch, 1833)			▦		▦						▦		▦			
Pardosa mixta (Kulczyn'ski, 1887)			▦		▦		▦		▦		▦					
Pardosa nigra (C. L. Koch, 1834)	▦		▦		▦						▦					
Sitticus longipes (Canestrini, 1873)							▦									
Xysticus desidiosus Simon, 1875																
Xysticus gallicus Simon, 1875													▦			