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The impact of high-altitude ski pistes on ground-dwelling arthropods in the Alps

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Abstract

The development of winter sport resorts above the timberline may affect every ecosystem component. We analyzed the effect of ski-pistes on the abundance and species richness of arthropods (namely carabids, spiders, opilionids and grasshoppers) trapped in grasslands adjacent to the ski-run, on ski-pistes and at the edge between these two habitat types.

Our results showed that diversity of brachypterous carabids, spiders and grasshoppers decreased significantly from natural grasslands to ski-pistes. This was not true for the macropterous carabid guild, which included species with contrasting ecological requirements.

The analysis of indicator species (IndVal) showed that most of the species (some of them precinctive to restricted areas in the western Italian Alps) had clear preferences for natural grassland and few taxa were limited to ski-pistes. Generalized linear models suggested that the local extent of grass and rock cover can significantly affect assemblages: the low grass cover of ski-pistes, in particular, was a serious hindrance to colonisation by spider, grasshopper, brachypterous and some macropterous carabid species. The results obtained, support concerns over the possible disruption of local ecosystem functionality and over the conservation of arthropod species which are endemic to restricted alpine areas. In order to retain arthropod ground-dwelling fauna we suggest that: i) new, environmentally friendly

ways of constructing pistes should be developed to preserve as much soil and grass cover as possible; ii) existing ski-pistes should be restored through management to promote the recovery of local vegetation.

Key words: diversity, ecosystem functioning, grasshoppers, ground beetles, opilionids, spiders.

Introduction

True alpine habitats are treeless zones above the natural tree line, with long-lasting snowfields, rocky ridges and continuous to scattered tundra vegetation (the so-called alpine belt). Alpine zones have increased in value as wildlife habitat, due to changes in habitats and processes at lower altitudes (Martin 2001). Some animal species that formerly used habitats over a broad range of elevations are becoming restricted to the upper elevations of their former range due to intensive agricultural and forestry activities (Martin 2001). Threats to ecological conditions of these high-altitude habitats are mostly anthropogenic and include both ultimate and local factors. Climate is probably the best ultimate predictor of where alpine zones begin (Körner 2003) and climate change has therefore strong impacts on the environment at high elevations (Inouye et al. 2000). Changes in temperature and moisture availability increase the growth rates, abundances and elevational ranges of many alpine plants at higher elevations (Körner 2003). However, with the increasing altitude of tree line, alpine habitats will become more fragmented, with small and isolated patches. Vertebrates and invertebrates living in these patches will have smaller populations and be required to disperse longer distances to other alpine patches, or pay the consequences of not dispersing (Martin et al. 2000; Roland et al. 2000).

The local impact on the high-altitude environment is recent, and is essentially the result of the development of winter sport resorts. From the beginning of the 20th century, the construction of buildings, access roads and the direct damage to fragile vegetation by machinery and skiers, have severely disturbed the environment in the Alps (Simons 1988; Mackenzie 1989). The establishment of ski-pistes, in particular, affects every ecosystem component (i.e. soil, plant and animal communities) because alpine grasslands and pastures are abruptly clear-cut (so that there is a distinct edge to the piste), and bulldozers and power shovels are used for soil removal to provide suitable slopes for skiers (this is often referred to as machine grading). These interventions affect soil properties and cause substantial loss of

organic carbon, organic cements and fungal hyphae (Delgado et al. 2007). Machine-graded pistes have lower vegetation cover, productivity, species diversity and abundance of early flowering species, and higher proportions of bare ground, leading to surface run off and erosion (Barni et al. 2007; Wipf et al. 2005). Soil and vegetation are also damaged by skiing and ski-piste preparation by snow-grooming vehicles (Cernusca et al. 1999; Rixen et al. 2003; Rixen et al. 2004a; Rixen et al. 2004b).

Global warming and the need to extend the duration of the skiing season encourage the use of artificial snow, which produces a different snow-pack compared to natural snow. The prolonged artificial snow cover induces a delay in snowmelt and soil warming at the end of the season (Rixen et al. 2004b; Keller et al. 2004b) and may cause a delay in the re-sprouting of vegetation (Rixen et al. 2003; Freppaz et al. 2007). Artificial snow can also add pollutants (such as oil from snow-producing machines) and biotic additives to soils (Rixen et al. 2003). Furthermore, in summer, cutting of shrubs and machine-grading are carried out at regular intervals in order to remove obstacles and level rough or bumpy soil surfaces (ground levelling), producing further damage to soil and vegetation (Bayfield 1996; Titus and Tsuyuzaki 1999; Barni et al. 2007).

Studies concerning the impact of the ski industry on animals above the timberline are few. Ptarmigans (*Lagopus mutus*) may suffer adverse impacts of ski-development on breeding success (Watson and Moss 2004) and population reductions due to collisions with ski-lift wires (Holden 1999). Alpine grassland bird communities tend to avoid ski-pistes and, to a lesser extent, nearby grasslands as well (Rolando et al. 2007).

In spite of the results obtained on birds, there is a dearth of studies of the effects of the ski industry on other animals of the alpine belt. New research on animal communities and/or assemblages is therefore required.

Alpine ground dwelling arthropods (namely ground beetles, grasshoppers, spiders, opilionids), in particular, require research for at least two main reasons.

1) Such arthropods (which are abundant, rich in species and ecologically diverse) are of prime importance for alpine ecosystem functioning, Spiders and most ground beetles are predators that play a key role in regulating populations of soil invertebrates and serving as prey for salamanders, small mammals and birds (Clarke and Grant 1968; Hance 1990). Grasshoppers may be abundant during summer when they become an important resource for typical alpine birds (Rolando and Patterson 1993; Rolando and Laiolo 1997). In the framework of the BEF (Biodiversity and Ecosystem Functioning) approach (Loreau et al. 2001; Hooper et al. 2005; O'Connor and Crowe 2005), any substantial impact of ski-pistes on diversity of these assemblages may therefore induce a disruption of local ecosystem functionality, which, in turn, may hinder the recovery of original natural habitats.

2) The Alps are a true hot spot of ground-dwelling arthropod diversity. With regards to ground beetles, for example, more than 25% of the total number of species occurring in the southern Italian Alps (some 800 species) are endemic (Casale and Vigna Taglianti 2005). Some of these species may qualify as endangered because they are found in few sites and/or are characterized by small population size. Recent surveys have shown that large-bodied, specialist, and brachypterous carabids are more subject to decline because of rapid changes in the environmental structure of their habitat (Kotze and O'Hara 2003). The construction of ski-pistes in diversity hot-spots is obviously of particular conservation concern. We therefore focused on a ski resort (Gressoney Valley) in the Monte Rosa massif, which is a well known Pleistocene refuge for many endemic taxa (Casale and Vigna Taglianti 1993).

To assess the impact of ski-pistes on the assemblages of ground dwelling-arthropods, we examined the structure of assemblages of carabids, spiders, grasshoppers and opilionids (expressed as total abundance and species richness) by trapping (pitfall traps) on ski-pistes, on adjacent grassland and at the edge (i.e. the straight line) between the two habitats. Pitfall trapping was one method available to assess the

abundance of surface active arthropods (Leather 2005), even though, it is biased by differential activity. Relationships between arthropod assemblages and the environmental characteristics of ski-pistes were analysed to identify the best predictors of local diversity. Species identities were taken into account to reveal both endemic species of conservation concern potentially threatened by ski-pistes, and any species that may instead benefit from them.

Material and Methods

Study area

The study was conducted on ski-pistes and in high altitude grasslands located at the top end of the Gressoney Valley, in the north-western Italian Alps (Aosta Valley, 45°51'22"N; 7°50'41"E).

The survey area is located within one of the Alps' most important ski districts (Monterosa Ski), with 180 km of ski-pistes and ski-lifts and an hourly flow of more than 50 000 people (www.monterosa-ski.com). The climate is continental with mean temperatures varying from -3,6°C in the coldest month (January) to 12,7°C in the warmest month (July). Annual rainfall (1 202 mm average) could be defined as "Mediterranean" with two maxima in May and October and two minima in July and December-January.

Around the timberline, coniferous forests (which are thin and characterized by larch *Larix decidua*) are interspersed with patches of alpine moorland (composed of *Vaccinium uliginosum*, *V. myrtillus*, *Rhododedron ferrugineum* and *Juniperus nana*). Above the timberline the typical vegetation of pastures on acid or acidified substrates is found, dominated by grasses such as *Carex curvula*, *Nardus stricta* and geophytes such as *Arnica montana*, *Pulsatilla alpina* and *Trifolium alpinum*. On the steeper slopes above 2 500 m environmental conditions limit the formation of the soil and patches of alpine pasture alternate

with debris. Above 3 000 m a.s.l., rocks, scree and snowbeds dominate the alpine landscape, up to the highest peaks and glaciers of Monte Rosa (4 634 m a.s.l.).

On ski-pistes the pre-existent habitat, top soil and vegetation had been completely removed and cover, both artificial and recovering grass, was poor. Ski-runs were 20-50 m wide.

Sampling design

Within the Gressoney ski district we selected 48 sampling plots spread over several ski-pistes and set at a minimum of 200 m linear distance from the nearest neighbour plots. Plots varied in altitude, from 2 500-2 900 m a.s.l., vegetation and rock cover as previously indicated. Three pitfall traps (aligned at 20 m intervals) were placed at each sampling plot: one was placed on the pasture adjacent to the ski-run, one on the ski-piste and one at the edge between the two habitats.

Pitfall traps were placed at the beginning of July 2007 and emptied fortnightly until the end of September (six sampling periods). They were 7.5 cm in mouth diameter and 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. A flat stone was placed 3 cm above each trap to prevent excess leaf litter, forest debris and rainwater from entering the traps.

The exact location of pitfall traps was established in the field by means of a Global Positioning System (GPS) Garmin eTrex® navigator.

Ground beetles, opilionids and spiders were sorted and identified, whenever possible, to species level using updated standard keys or specialists works. Nomenclature follows Platnick (2008) for spiders, Audisio and Vigna Taglianti, (2004) for ground beetles and Martens (1978) for opiliones.

A number of spider species were only present as juveniles and could not be identified beyond genus level. In agreement with several authors (e.g. Krell 2004; Kapoor 2008), such individuals were included as morpho-species (hereinafter indicated with the name of the genus followed by sp.). Spiders can be collected by means of several sampling techniques: by using pitfall traps, we mainly detected wandering species. Over the course of the study it became apparent that pitfall traps were also capturing grasshoppers. They were therefore collected, preserved in alcohol and identified *a posteriori*, as already done by Clayton (2002). We acknowledge that pitfall trapping, although it is widely used for mole crickets (Barbara and Buss 2006; Adjei et al. 2003), and true crickets (Ribas et al. 2005; Velez and Brockmann 2006), may not be an appropriate sampling method for most Orthoptera. However, given that the same sampling method was used in all the different habitats, we are confident that results are reliable (albeit, maybe not systematically exhaustive) to compare assemblages of natural and modified habitats. Grasshoppers were identified to species level (following Fontana et al. 2002). We have not considered other arthropods of the soil, such as Myriapods, Crustacea, Mites and Collembola, because of the very low number of individuals sampled.

Habitat structure characteristics of each habitat type (i.e. ski-piste, edge and natural grassland) were recorded for each trap: in circular areas of 2 m radius centred on the pitfall trap we measured grass cover, soil-rubble cover , rock cover (estimated by eye) and mean grass height (ten measurements randomly located, in centimetres). Slope and altitude were also recorded.

Data analysis

A potential total of 144 samples were obtainable (48 plots x 3 traps) per sampling period and a total of 864 samples was obtainable altogether (144 x 6 sampling periods). However, several traps were damaged

by tourists and ibexes (*Capra ibex*), or inactivated by heavy rain, and were excluded from statistical analyses.

Sampling plots were set on different ski-pistes and at proper inter-plot distance (Leather 2005) to meet the statistical assumption of independence.

Differences among habitat types

For ground beetle and spider assemblages, which were highly diversified, with several species, two diversity parameters were calculated for each trap: species richness (S) and total abundance (N). Parametric tests (such as Two-way ANOVA) could not be properly employed because several assumptions were not met. In particular, variances of samples were not equal (i.e. homoscedasticity was violated) and error terms were not always normally distributed (even after appropriate data-transformation) [violations were assessed through the Levene's test and the Normal Probability plot, respectively (Sokal and Rohlf 1995)]. Because of these violations, differences in mean species richness and abundance between the three habitat types and the six sampling periods were tested by means of a generalized linear model (GLM) considering two categorical factors (habitat type and sampling period). Abundance and species richness attained a Poisson distribution; therefore a Poisson distribution of errors was assumed and the density of ground-dwelling arthropods was related to explanatory variables via a logarithmic link function (McIntyre and Lavorel 1994).Tests for the significance of the effects in the model were performed by means of the Wald statistic (Dobson 1990).

Such statistics is based on the asymptotic normality property of maximum likelihood estimates and is computed as the generalized inner product of the parameter estimates with the respective variance-covariance matrix. Moreover, we explored the habitat factor estimates, their standard errors and individual statistical significance.

Generalized linear models with categorical variables and Wald statistic were calculated using the STATISTICA 6.0 package (StatSoft Italia srl 2001). According to this package, if one selects to use the sigma-restricted parameterization the last category that is specified for a categorical variable is the reference category (or level) and hence only pairwise comparisons between the effects of the remaining levels of the predictor variable on the response (dependent variable) are allowable. According to the parameterization chosen the estimation of each parameter refers to the additional effect on the dependent variable of a particular level of the considered predictor, depending on the link function chosen, with respect to the reference one and holding the other possible predictors at a constant level. In the habitat parameter estimation analysis we used ski-piste as the reference category.

Ground beetle assemblages may be composed of species with contrasting ecological requirements so that ecological patterns could not be appropriately revealed (Negro et al. 2009). Accordingly, carabids were divided into two main ecological groups based on their wing morphology: macropterous (full-sized wings) and brachypterous (reduced wings or wingless). Data on flight ability were obtained from the literature (Brandmayr et al. 2005) or by inspection of individuals collected when wing condition was not already known.

For poorly diversified assemblages (opilionids and grasshoppers), community parameters were not computed and the impact of ski-pistes was evaluated by comparing the observed number of individuals trapped in each habitat type with the expected number which, on the assumption of no preference among habitats, was proportional to the sampling effort for each habitat (i.e. $\sum_{i=1}^{n} t_i$ where t_i is the number of active traps per sampling day and n the total number of sampling days). High specificity and fidelity of every ground beetle and spider species within habitats were explored by the IndVal (Indicator Value) procedure (Dufrêne and Legendre 1997). The indicator value is highest (100) when all individuals of a species are found in a single habitat (high specificity) and when the species

occurs in all samples of that habitat (high fidelity). The statistical significance of the maximum indicator value was evaluated by a Monte Carlo randomization test (1 000 runs). IndVal analyses were run using PC-Ord software (McCune and Mefford 1999).

Relationships between arthropod assemblages and habitat

Environmental characteristics were analysed in order to identify the best predictors of local diversity of ground beetles and spiders. Since habitat structure variables were correlated, much of the information in one or more of these can be redundant and thus the results of analyses based on these raw predictors might be ambiguous (Jongman et al. 1995). Principal Component Analysis (PCA, Gaunch 1984) was chosen to minimize the effects of multicollinearity and to reveal patterns in the data using standardized data (zero mean and unit standard deviation) (Legendre and Legendre 1998).

To reveal relationships between abundance and richness of arthropods (ground beetles and spiders) and environmental variables, we used generalized linear models (GLM).

Akaike's information criterion (AIC, Akaike 1973) was chosen to select the most appropriate models, i.e. those fitting best the available data set. AIC is based on the principle of parsimony and helps to identify the model that accounts for the most variation and the fewest variables: the model that best explains the data is that with the lowest AIC. This information criterion is one of the most powerful approaches for model selection from a set of alternative plausible models and it solves the problems of stepwise model selection because no sequential statistical test is conducted (Burnham and Anderson 1998).

Generalized linear models with environmental variables and Wald statistic were calculated using the STATISTICA 6.0 package (StatSoft Italia srl 2001)

Results

A total of 5,627 individuals, representing 54 different species, were collected altogether (Appendix 1). Carabids were numerically predominant because they accounted for 46.9% of the total number of individuals collected (i.e. 2 639 individuals), followed by opilionids (23.7%), spiders (22.2%) and grasshoppers (7.2%). Spiders dominated in terms of species richness (at least 44.6% of species, i.e. 25 species), followed by ground beetles (39.3%), opilionids (8.9%) and grasshoppers (7.2%).

The relative abundance of species within each higher taxon varied. One species dominated in opilionids (*Mitopus morio*, 99.4% of individuals) and carabids (*Carabus concolor*, 69.3%), whereas two species were abundant in grasshoppers (*Aeropus sibiricus*, 49.5% and *Podisma pedestris*, 40.1%). Spiders were more evenly structured with three species having over 10% of individuals each (i.e. *Coelotes pickardi pickardi*, 21.3%; *Drassodes cupreus*, 16.8%; *Haplodrassus signifer*, 11.2%).

Some species were of conservation interest because they are precinctive (or endemic) to more or less restricted geographic areas (Appendix 1). Eight species were endemic to the Alps (*Ocydromus rhaeticus* and *Oronebria picea* among ground beetles; *Anonconotus alpinus* among grasshoppers; *Zelotes devotus*, *Meioneta alpica* and *Sitticus longipes* among spiders and *Mitopus glacialis* and *Dicranopalpus gasteinensis* among opilionids) and eight taxa were restricted to the western part of the chain (*Carabus concolor*, *Carabus latreilleanus*, *Cychrus cordicollis*, *Platynus complanatus*, *Pterostichus cribratus* and *Pterostichus parnassius* among ground beetles; *Megabunus rhinoceros* among opilionids; *Coelotes pickardi pickardi* among spiders).

Carabids accounted for the largest number of locally endemic species (36.4%, i.e. 8 species out of 22 collected altogether).

Differences among habitat types

Total abundance and species richness of spiders and brachypterous carabids significantly differed between habitat types (ski-piste, edge and natural grassland, Table 1, Fig. 1, 2). Alternatively, abundance and richness of macropterous ground beetles did not vary.

These parameters also significantly changed among sampling occasions (with the only exception of the species richness of brachypterous carabids). Interactions between factors were significant when the dependent variable was abundance (Table 1).

Estimates showed that abundance and species richness of spiders on ski-pistes were significantly lower than in both grasslands and edges, whereas abundance and species richness of brachypterous carabids on ski-pistes were significantly lower in grasslands only (Table 2).

The abundance of all species of grasshoppers (*Podisma pedestris*, *Aeropus sibiricus*, *Melanoplus frigidus* and *Anonconotus alpinus*) progressively decreased from natural grasslands to ski-pistes. Differences between the observed total number of individuals trapped and the expected number were significant (χ^2 = 61.32; d.f. = 2; $P < 0.001$) (Fig. 3).

A reverse trend was observed in opilionids (disproportionately represented by a single species, *Mitopus morio*), that were more abundant on ski-pistes (χ^2 = 119.02; d.f. = 2; $P < 0.001$).

The analysis of indicator species by IndVal showed that all brachypterous carabids (*Carabus concolor*, *Carabus latreilleanus*, *Pterostichus cribratus*) and most spiders (*Haplodrassus signifer*, *Micaria alpina*, *Pardosa blanda*, *Pardosa mixta*, *Xysticus desidiosus* and *Drassodes cupreus*) preferred natural grasslands. Macropterous carabids did not show the same preference pattern because indicator species were evenly distributed among habitat types: two species preferred natural grasslands (*Harpalus solitaris* and

Cymindis vaporariorum), two edges (*Amara erratica* and *Platynus complanatus*) and two ski-pistes (*Amara quenseli* and *Ocydromus incognitus*) (Table 3).

Relationships between arthropod assemblages and habitat

The first two principal components (PC1 and PC2) accounted for 78.2% of the total variation in the habitat structure matrix, with eigenvalues >1 (Table 4). The percentage of grass cover provided the major positive loading and the percentage of rock cover the major negative loading on PC1 (suggesting a grassy gradient from high grass cover of natural grasslands to low grass cover of ski-pistes). The percentage of soil-rubble cover showed the highest positive correlation with PC2 scores.

The relative position of pitfall traps in the PC1 x PC2 biplot made two distinct clusters, that separate ski-pistes from natural grasslands (Fig. 4).

Results of generalized linear models of brachypterous carabid and spider richness and abundance on environmental predictors (namely altitude, slope, PC1 and PC2) are shown in Table 5 [given that community parameters significantly varied throughout the season (Table 1), the sampling period was also taken into account as a covariate]. Macropterous carabids were omitted from these analyses because of the lack of differences among habitat types. All diversity parameters considered (abundance and richness) were positively associated with PC1, thus suggesting that diversity increased along with grass cover. Other significant predictors were altitude, which was positively associated with the abundance of brachypterous carabids and spiders (Table 5).

Discussion

In machine-graded ski-pistes herbaceous cover and specific composition, root density and physico-chemical soil properties change significantly with respect to undisturbed grasslands (Barni et al. 2007). Our results indicate that these environments, in addition to soil and vegetation modification, also suffer from extensive arthropod depletion. In particular, diversity of brachypterous carabids, spiders and grasshoppers decreased progressively from undisturbed natural grasslands to ski-pistes. Macropterous ground beetles have more varied ecological requirements (some positively selected natural grasslands and some ski-pistes, IndVal).. Surface-active arthropods (brachypterous carabids, spiders) are known to be more active on bare ground than in dense grassland: this suggests that true abundances on the open pistes may have been lower than was indicated by numbers in pitfall traps. In contrast, macropterous carabids are vagile species which fly frequently and so catching efficiency of traps in bare ground and dense grassland were probably equivalent. GLM analyses indicated that grass cover on a small scale significantly affected catches of brachypterous carabids and spiders, because diversity parameters increased along with grass cover. Low grass cover of ski-pistes appeared to be a serious impediment to colonisation by spider, grasshopper and brachypterous ground beetle species.

Biological communities are threatened through a variety of activities that increase rates of species invasions and species extinctions at all scales, from local to global (Hooper et al. 2005). These changes have a potential to alter ecosystem properties and the goods and services they provide (Loreau et al. 2001; Hooper et al. 2005), known as the biodiversity ecosystem functioning (BEF) hypothesis. The central tenants of the BEF hypothesis are that an ecosystem with more species will process resources more efficiently, be more productive, be more stable over time and be less subject to invasions than an ecosystem with fewer species (Beisner and Romanuk 2006). When alpine grassland is converted to bare ground typically it does not revegetate for decades (Martin 2001). We suggest that the disruption of ski-piste food webs may be partly responsible for their slow rate of natural restoration.

Alpine arthropods (particularly herbivore taxa) in natural grasslands are known to accelerate ecosystem mineral cycling, because they reduce the high proportion of standing dead material and play a key role in the carbon-nitrogen balance, by concentrating nitrogen in faeces and herbivore biomass (Blumer and Diemer 1996). It is likely that reduction of ground-dwelling arthropods on ski-pistes may be partly responsible for the avoidance of these linear patches by alpine birds which prey upon them (in keeping with Rolando et al. 2007).

A few species were significantly positively associated with this disturbed habitat. The macropterous ground beetle species *Amara quenseli* and *Ocydromus incognitus,* which are known to prefer open and moist environments respectively, should have found these environmental conditions on ski-pistes. The reasons for the abundance of the dominant opilionid *Mitopus morio* on ski-pistes (more individuals were caught on ski-pistes than in the other two habitats) could be different. Opilionids are able to walk through dense vegetation by wrapping their bendable tarsi around small twigs and blades of grass. It can be assumed (Axel Schoenhofer pers. comm.) that in natural grasslands animals were prevented from falling into pitfall traps by the presence of three-dimensional pathways, while on ski-pistes (where plant cover was often missing or highly reduced) they were easily trapped; an example of the effect of habitat on trap catches. This study showed that, as pointed out for forest ski-pistes (Negro et al. 2009), a guild-based approach is valuable in understanding more fully the consequences of anthropogenic impacts. Brachypterous carabids are medium-large species, wingless or with reduced wings, incapable of long distance movement (Den Boer 1970; Negro et al. 2007; 2008). Alpine ski-pistes are linear environmental elements which may potentially prevent or reduce movements between adjacent grassland patches. Mader (1984) observed that spiders and carabid beetles never crossed a lightly travelled paved road six metres wide and also tended to avoid the grassy roadsides. Mark-release studies demonstrated that only eurytopic open-habitat ground beetle species were able to cross highways in forested areas, the other species being unable to cross (Koivula and Vermuelen 2005). Large roads also led to significant intraspecific genetic differentiation in abundant flightless carabids (Keller et al. 2004a). Future studies on marked individuals

would be useful to confirm whether ski-pistes really do act as ecological barriers to ground-dwelling arthropods. Radio-tracking, successfully tested on large carabids (Negro et al. 2007; 2008), might be particularly useful in this context.

Ground-dwelling arthropods receive little attention from a conservation standpoint. Only one ground beetle species (*Carabus olympiae*) and one spider species (*Macrothele calpeiana*) have international conservation significance (both species are listed in the Annex IV of the 92/43/EEC Habitat Directive). Nevertheless, alpine arthropods and, in particular, ground beetles, deserve high conservation priority because, in addition to the ecological roles they play, several species have restricted distributions and have suffered alarming population declines. Recent surveys carried out in several European countries showed that large-bodied, locally endemic and brachypterous ground beetles are increasingly prone to extinction risk because of habitat transformation (Kotze and O'Hara 2003). Some medium-to-large ground beetle species which were identified by IndVal as typical grassland species, i.e. *Carabus concolor*, *Carabus latreilleanus* and *Pterostichus cribratus*, are of conservation interest because they are endemic to more or less restricted alpine areas (Casale and Vigna Taglianti 1993).

In the spiders, the subspecies *Coelotes pickardi pickardi* was locally endemic to the Monte Rosa Massif, whereas the three species *Meioneta alpica*, *Sitticus longipes* and *Zelotes devotus* were restricted to the Alps and only found at the highest altitudes.

Among opilionids, *Megabunus rhinoceros* (three individuals caught on natural grasslands) was approximately confined to the Aosta Valley (the locus typicus is restricted to the Monte Rosa massif where our study area was located).

Similarly, the grasshopper *Anonconotus alpinus* (six individuals trapped in natural grasslands), deserved high conservation priority because has survived in only few glacial refugia (such as the Monte Rosa massif) of the southern Alps (Galvagni and Fontana 2004).

In order to fully understand the potential impact of ski-pistes in the Alps, it should be noted that the total length of pistes might be several thousands of kilometers (Rolando et al. 2007) and that, in order to accommodate global warming, ski-pistes could in the future be constructed at higher altitudes, where ecosystems are more fragile and vulnerable.

To retain the arthropod fauna of the region of ski resorts, new, environmentally friendly ways of constructing pistes should be developed. Rocks only should be removed and only the roughest (and most dangerous for skiers) ground surfaces should be leveled in order to preserve as much soil and natural vegetation as possible. In all alpine areas ski-pistes should be restored through management to prevent soil erosion and promote the recovery of local vegetation. Transplantation of single plants (Florineth 2002) or turf transplants of wild alpine species to create a wholly autonomous community (Urbanska 1997a,b; Conlin and Ebersole 2001; Ebersole et al. 2002) are promising methods.

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	Abundance Distribution: POISSON Link-function: LOG			Species richness Distribution: POISSON Link-function: LOG		
	DF	Wald Stat.	*p*	DF	Wald Stat.	*p*
Brachypterous carabids						
Habitat type	2	221.554	**0.000**	2	11.820	**0.003**
Sampling period	5	142.940	**0.000**	5	8.048	0.154
Habitat type*Sampling period	10	24.178	**0.007**	10	4.765	0.906
Macropterous carabids						
Habitat type	2	0.155	0.925	2	0.731	0.694
Sampling period	5	358.501	**0.000**	5	139.546	**0.000**
Habitat type*Sampling period	10	31.408	**0.001**	10	13.372	0.204
Araneae						
Habitat type	2	86.368	**0.000**	2	32.374	**0.000**
Sampling period	5	61.747	**0.000**	5	18.360	**0.003**
Habitat type*Sampling period	10	38.391	**0.000**	10	8.628	0.568

Table 1. Tests for the significance of the effects (habitat type and sampling periods). Analyses were performed by means of the Wald statistic. The significant *p*-values are in bold type.

	Abundance Distribution: POISSON Link-function: LOG				Species richness Distribution: POISSON Link-function: LOG			
	Estimate	SE	Wald Stat.	*p*	Estimate	SE	Wald Stat.	*p*
Brachypterous carabids								
Edge	0.031	0.035	0.816	0.366	0.005	0.061	0.008	0.929
Natural grassland	0.524	0.031	289.435	**0.000**	0.177	0.057	9.813	**0.002**
Araneae								
Edge	0.154	0.048	10.206	**0.001**	0.161	0.061	6.885	**0.009**
Natural grassland	0.467	0.045	110.020	**0.000**	0.297	0.058	26.063	**0.000**

Table 2. Habitat factor estimates, their standard errors, and statistical significance.

In this analysis ski-piste habitat type is set as reference category. Significant comparisons are in bold type.

Species	Habitat	Observed Indicator Value (IV)	IV from randomized groups		p
			Mean	S.Dev	
Brachypterous carabids					
Carabus concolor	Natural grassland	44.5	29.9	1.68	***
Carabus latreilleanus	Natural grassland	8.9	6.6	1.17	*
Pterostichus cribratus	Natural grassland	15.3	7.5	1.16	***
Macropterous carabids					
Harpalus solitaris	Natural grassland	2.4	1.3	0.55	*
Cymindis vaporariorum	Natural grassland	19.0	5.7	1.06	***
Amara erratica	Edge	5.4	3.1	0.88	*
Platynus complanatus	Edge	3.6	1.6	0.61	*
Amara quenseli	Ski-piste	11.6	7.2	1.19	**
Ocydromus incognitus	Ski-piste	13.2	3.3	0.96	***
Araneae					
Haplodrassus signifer	Natural grassland	13.7	7.3	1.18	***
Micaria alpina	Natural grassland	4.1	1.8	0.63	**
Pardosa blanda	Natural grassland	7.4	4.0	1.17	*
Pardosa mixta	Natural grassland	14.2	4.7	1.15	***
Xysticus desidiosus	Natural grassland	6.3	3.3	0.83	**
Coelotes pickardi pickardi	Edge	14.5	12.2	1.42	(*)
Pardosa nigra	Edge	4.9	2.8	0.82	*

Table 3. Indicator Species Analysis (IndVal). Species which significantly indicate one of the three habitat type are shown. Maximum observed value and mean expected (± SD) indicator value are given. Statistical significance obtained by Monte Carlo randomization test (1 000 runs). (*) P < 0.07; * P < 0.05; ** P < 0.01; *** P < 0.001.

	Factor loadings	
Variables	PC1	PC2
grass cover	**0.977**	0.007
soil-rubble cover	-0.266	**0.909**
stone-rock cover	**-0.911**	-0.402
mean grass height	0.439	-0.299

Table 4. Results of a Principal Component Analysis carried out on four habitat variables measured for

Predictor	Estimate	SE	Wald stat.	p
Brachypterous carabids				
Abundance				
Altitude	0.003	0.000	74.249	<0.001
PC1	0.453	0.027	282.170	<0.001
Sampling period			178.812	<0.001
AIC = 3038.2				
Richness				
PC1	0.163	0.047	12.055	<0.001
AIC = 1041.7				
Araneae				
Abundance				
Altitude	0.003	0.000	31.050	<0.001
PC1	0.472	0.037	159.586	<0.001
Sampling period			107.935	<0.001
AIC = 2198.1				
Richness				
PC1	0.311	0.048	42.486	<0.001
Sampling period			26.055	<0.001
AIC = 1374.6				

each trap in a circular area of 2 m radius. The highest factor loadings are in bold type.

Table 5. Generalized linear models of spiders and carabid (brachypterous and macropterous groups) community parameters, in relation to environmental predictors (PCA scores, slope and altitude). Only significant variables included in the best model (i.e. that minimizing AIC) are shown; variables were added sequentially.

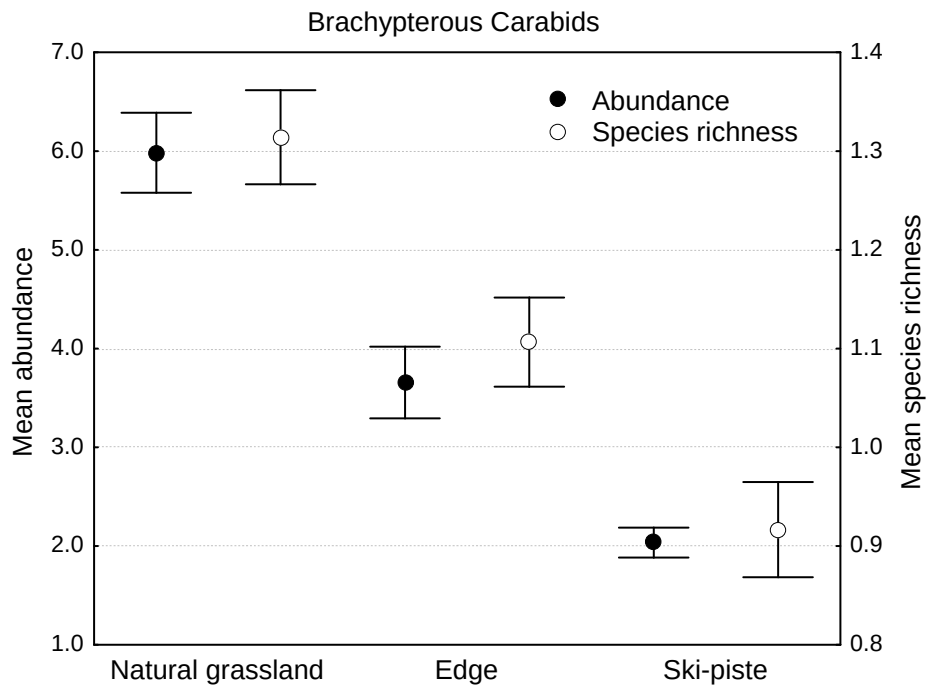

Fig. 1. Mean species richness and abundance of brachypterous carabids on natural grassland, edge and ski-piste habitats. Bars are ± standard errors.

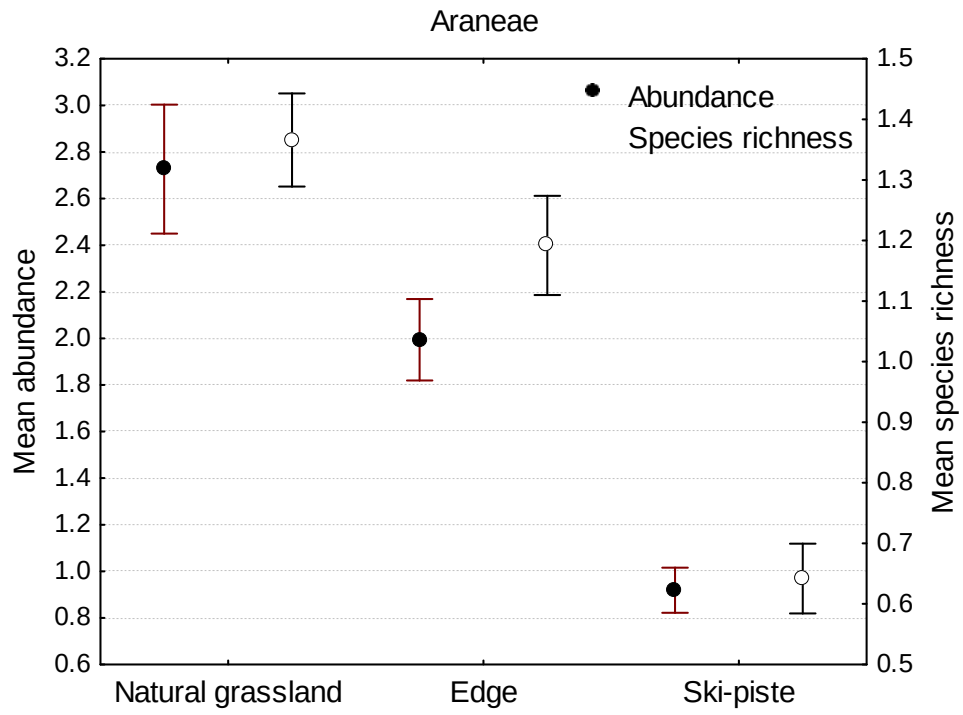

Fig. 2. Mean species richness and abundance of Araneae on natural grassland, edge and ski-piste habitats. Bars are ± standard errors.

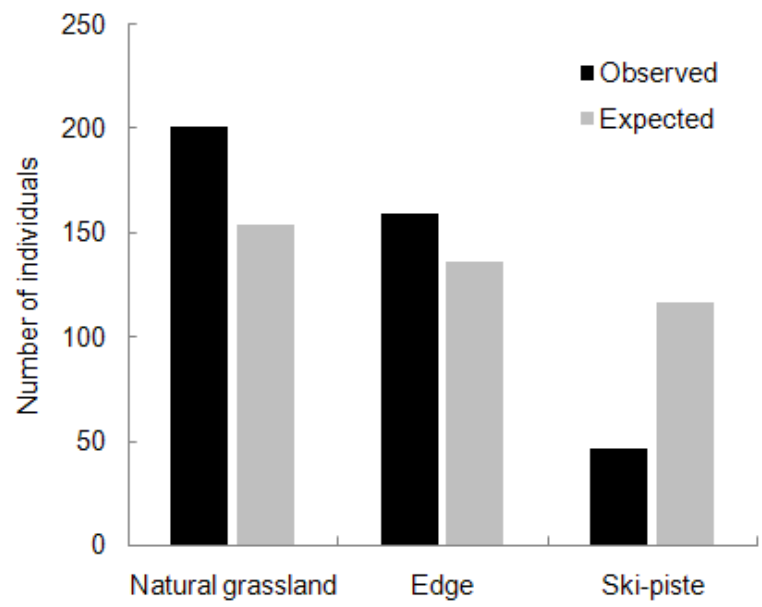

Fig. 3. Total number of Orthoptera observed and expected in each habitat type (natural grassland, edge and ski-piste). Differences were significant (χ^2 = 61.32; d.f. = 2; P < 0.001). The total number of individuals caught was 406.

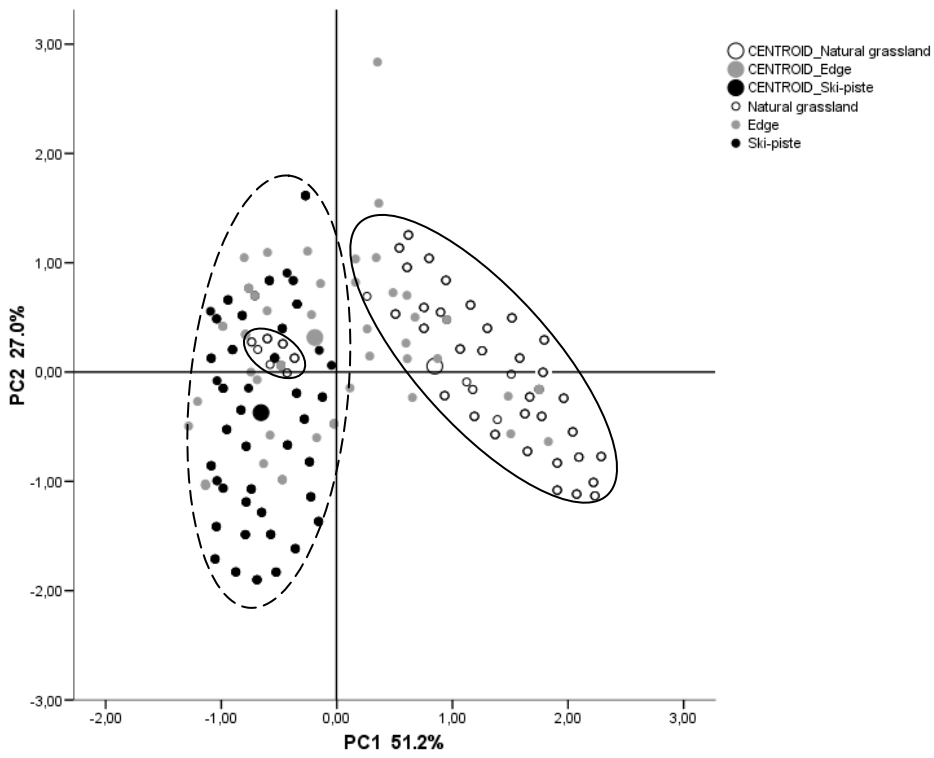

Fig. 4. Biplot of a Principal Component Analysis (PC1 vs. PC2). Distribution of pitfall traps and relative centroids are shown. Dashed and continuous ellipsoids delimit ski-piste and natural grassland pitfall traps, respectively. Note that traps located in grasslands at high elevation (about 2 900 m a.s.l.) are clustered together with those located on ski-pistes because of low grass cover there (small continuous ellipsoid).