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ORIGINAL PAPER

The effect of local anthropogenic habitat heterogeneity on assemblages of carabids (Coleoptera, Caraboidea) endemic to the Alps

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Abstract We assessed the response of a guild of endemic medium and large-bodied carabid species to the local (fine-grained) habitat heterogeneity induced by man. The study was conducted by means of trapping (without killing and preservative agents) and radio-tracking methods (to collect data on the spatial ecology of the endangered species *Carabus olympiae* Sella). Habitat differentiation induced by man (a mosaic of beech forests, alpen rose shrubberies and pastures) affected species richness and abundance of the guild, which were significantly higher in forests and/or shrubberies than in pastures. Most species preferred forests and shrubberies, with the only exception of *Carabus concolor* Fabricius, which preferred open areas. Species distribution was also affected by stone density and cattle grazing intensity. In particular, petrophilous species peaked on the roadside because of the high stone density there (stones amassed during road construction), while species abundances significantly lowered in overgrazed pastures. The compactness of the paths made by *C. olympiae* individuals (evaluated through a tortuosity index) was significantly higher in beech forests than in alpen rose shrubberies, indicating movements in the latter habitat type were bound by the spatial distribution of shrubs, which imposes a limit on path tortuosity. Our findings suggest that local ground beetle species diversity strongly depends on small-scale anthropogenic variables (namely habitat type, stone density and grazing intensity), and that habitat modifications (namely from forest to shrubbery) may significantly affect species movement patterns. General and local conservation management suggestions are given in conformity with these results.

Keywords Endemic species · ground beetles · grazing intensity · habitat types · pitfall trapping · proximity to roads · radio-tracking · stone density

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Introduction

A major contributing factor to the global loss in animal biodiversity is anthropogenic impact in the environment, with land-use change being acknowledged as one of the more significant drivers (Myers and Knoll 2001; Novacek and Cleland 2001). Forest fragmentation and subsequent replacement by agriculture or pastoralism is one of the most relevant land-use transitions.

Ground beetle assemblages are often used as surrogates of total animal biodiversity, and are usefully studied to assess the response of invertebrate communities to forest fragmentation and agricultural and/or pastoral intensification.

Effects of anthropogenic environmental heterogeneity on ground beetle biodiversity may be studied at different scales. At the macroscale (*sensu* Judas et al. 2002), ground beetle species may be classified in groups related to land cover variables (Eyre et al. 2003; Eyre and Luff 2004) and at the mesoscale (i.e. the landscape scale), there is evidence that patterns in land-use significantly affect beetle community structure producing distinct assemblages (Vanbergen et al. 2005). Fragmented forest-agro-pastoral landscapes are known to be high in ground beetle diversity. It has been predicted that biodiversity peaks at intermediate levels of disturbance, when competitive species would be suppressed facilitating colonization by less competitive species (Connell 1978). However, high diversity may be simply due to the fact that these eco-mosaics support both elements of close (forests) and open habitats (fields and pastures), in keeping with the predictions of the so-called ''edge effect'', i.e. the hypothesis that species richness and density increase at the border between different habitats (Odum 1971). Edge effects have been well documented for many carabid assemblages (Yu et al. 2006; Koivula et al. 2004; Magura 2002; Magura et al. 2004; Molnár et al. 2001; Petit and Usher 1998; de la Peña et al. 2003).

Anthropogenic environmental heterogeneity may also affect the diversity of carabid beetle assemblages at local micro-scale, and fine-grained studies may therefore be useful. For instance, analyses regarding local pastoral systems may provide not only information upon the effect of grazing (Gardner et al. 1997; Bhriain et al. 2002), but also succeed to reveal the proximate causes of these effects. At this scale, radiotelemetry may be usefully employed to track individual movements to understand how behavioural choices cope with local ecological heterogeneity.

When the replacement of forest systems with intensive agro-pastoral systems increases ground beetles diversity, one may be tempted to conclude that anthropogenic habitat heterogeneity would be beneficial for carabid diversity. This would be an obvious oversimplification as it fails to consider that biodiversity conservation is not only a question of maximising the number of species, but also the composition of the assemblage is important. For instance, it has been observed that larger bodied species are completely absent or much less common in agricultural landscapes (Vanbergen et al. 2005).

Hence, to be really useful in a conservation biology framework (Samways 2005), the study of the impact of anthropogenic habitat heterogeneity on ground beetles should take into account assemblages of uncommon and localized species and/or single endangered species (Assmann and Janssen 1999; Magurran 2004). Brachypterous (short-winged) ground beetle species with restricted geographic ranges, for instance, were indicated as conservation priorities in northern Spain (Gutiérrez et al. 2004).

In this framework, the southern Italian slope of the Alps represents a true hot spot of ground beetle diversity, given that some 800 species dwell in this area, 220 of which (i.e. more than 25%) are endemic, often localized to restricted biotopes (Casale and Vigna

Taglianti 2006). Some of these species may be qualified as endangered because they are found in very few sites and are also characterized by small population size. Recent surveys have shown that large-bodied, specialist (with small niche breadths) and brachypterous carabids are more subject to decline because of quick change in environmental structure of their habitat (Kotze and O'Hara 2003).

In this study, we focused on a guild of localized, medium and large-bodied brachypterous ground beetle species inhabiting a protected area in the Italian Alps. Our main aim was to assess the response of ground beetles to the local micro-scale habitat heterogeneity induced by man. The study was conducted through trapping and radio-tracking methods. Carabid beetles are usually sampled using pitfall trapping with killing and preservative agents. However, this sampling method may exert negative effects on populations of rare and/or endangered species. In our study area, almost all carabid species were of conservation concern because they were endemic to the western Alps, and a few species were also characterized by small population size. Therefore, we choose a capture-and-release approach, using traps with no killing and preservative agents to keep animals alive. Radio-tracked individuals were re-captured before the running out of the battery, deprived of the tag and released.

Study area

The fieldwork was carried out in Sessera Valley (45°40'16'' N; 8°05'07'' E, Biella province, Piedmont, north western Italy), where localized species of great biogeographical interest dwell (Casale and Vigna Taglianti 1993). The investigated site (about 37 ha, comprised between 1350 and 1450 m a.s.l.) is covered by beech *Fagus sylvatica* forests (namely, the *Luzulo-Fagetum* phytosociological association) intermingled with shrubberies (alpen rose *Rhododendron ferrugineum* L. and bilberry *Vaccinium myrtillus* L.) and pastures (dominated by graminaceous plants). The presence of pastures and shrubberies is due to a long history of tree fall followed by livestock animal disturbance, caused by grazing and trampling of cattle. At present an herd (of about 30 cows) is usually driven to these pastures every year from June to September. The construction of access tracks and roads to pastures and the removal of large stones from pastures and their use to build dry-stone walls and scattered heaps were other common anthropogenic local disturbances. Roads were rather narrow (3.33 m ± 0.24 m) and not asphalted.

The study area is located within a private protected area (Oasi Zegna) and it is also included in a Site of Community Importance (SIC) which was intentionally identified to protect a steno-endemic, paleo-relict, ground beetle species, namely *Carabus olympiae* Sella, 1855. This endangered species is considered as *priority species* (i.e. a species for the conservation of which the European Community has particular responsibility) and it is listed in the Annexes II and IV of the Habitat Directive (92/43/EEC).

Material and methods

Pitfall trapping

Ground beetle guilds of medium- and large-bodied carabids (i.e. more than 1 cm in length, all the other ground species in the area being much smaller, less than 1 mm) were sampled using pitfall trapping (Leather 2005). At each sampling plot, a regular 5 m × 5 m quadrat grid was considered. Eight traps (with plastic rain shields to prevent flooding) were randomly placed at vertices of quadrats comprised within a 20 m × 20 m area. The exact location of traps was established by means of a Global Positioning System (GPS) Garmin eTrex® Navigator.

Traps derived from plastic bottles that had been cut in two parts, one cylindrical and one conical, the later re-inserted upside down in the former. Technically, they consisted of a polypropylene cylindrical container, 8 cm diameter and 15 cm deep, in which a conical cup with the same diameter, 10 cm deep, was inserted, the perforated bottom (4 cm diameter) downward. The cylindrical cup was filled with vinegar as attractant (6 cm depth), the conical one with gravel to form a 2 cm thick bed whose inferior part was partly immersed in the vinegar below. No funnel was used because all species were brachypterous, with no or short, inefficient wings, and therefore unable to escape. Using this device, ground beetles which were caught stayed alive and, after identification, they were released at about one kilometre from the study area (with the exception of *C. olympiae*, see below), to avoid re-capture of the same individuals.

Traps were emptied at four days interval between 15 May and 30 September in 2004 and 2005. The catch was sorted and species identified in field using identification guides with updated nomenclature (Brandmayr et al. 2005). Sampling plots were located in different habitat types (see below), each habitat being sampled in both years with the same sampling effort (namely the same number of sampling plots/habitat type/year).

Radiotracking

Radiotelemetry was utilized to investigate habitat selection and movements of the priority species *C. olympiae*. Adult individuals were radio-tagged by using tiny tags (about 0.3 g, 15 mm × 5 mm × 4 mm, from Biotrack Ltd, Wareham, England, www.biotrack.co.uk) glued (with cyanoacrylate) on top of the elytrae, with the short antenna (2.5 cm) directed backwards. Signals could be detected from approximately 300 m, both when individuals stayed above the ground, and when they were buried in the leaf-litter or in the ground. The maximum life span of the tag battery was about 20 days. We located each tagged individuals twice a day, in early morning and at sunset. The exact location of fixes was established in the field by a GPS; a coloured peg was also driven into the soil, to avoid eventual GPS measurement errors. After location, the environmental characteristics of the fix were recorded and the linear distance from the previous fix was evaluated by means of a telemeter.

Data analysis

A total of 34 sampling plots representing all main habitat types and anthropogenic disturbances were positioned in the study area. At each sampling point explanatory categorical variables were collected to characterize the plot and to attempt to identify those factors structuring the beetle guild and affecting the presence of each species.

Five main variables were taken into account: (1) habitat type (five categories = grassland, thin [less than 50% coverage] alpen rose shrubbery, dense [more than 70% coverage] alpen rose shrubbery, thin [less than 50% canopy coverage, corresponding to 371.5 ± 62.6 trees/ha] beech forest, dense [more than 70% canopy coverage, 971.3 ± 59.6 trees/ha] beech forest; (2) geographical aspect (three categories = south, east and north); 3) proximity to country roads or mule-tracks (four categories: 20, 20–40, 40–100, and above 100 m); (4) density of stones (four categories: 30%, 20%, 10% coverage, and no stones); 5) altitude (two categories: above and below 1400 m a.s.l.). Canopy and stone coverage was estimated by eye. Tree density was inferred from circular sampling points with 20 m radius (six placed in thin and six in dense beech forest); only beeches with trunks larger that 15 cm in diameter were counted. Distances from roads were estimated through a telemeter.

For plots located in pastures grazing intensity was evaluated by taking into account two grazing intensity categories (high and low, evaluated on the seasonal presence of the herd of cows).

Ground beetle guild was described in terms of ground beetle species richness (S), density (D) and diversity (Shannon index: $H' = -\sum p_i x \ln p_i$ where p_i is the relative frequency of species *i*). We tested for differences in mean species richness, density and diversity of the three main habitat types (namely forests, shrubberies and pastures) by means of one-way ANOVA; least-squares deviation (LSD) post-hoc tests were used for pair-wise comparisons of habitat type means. To approach normality (checked by using normal probability plots), abundance and richness data were square-root transformed, diversity data were log transformed (Sokal and Rohlf, 1995).

We used generalized linear models (GLM) to test for the effects of environmental variables on diversity, abundance and richness of the carabid assemblage, and on the abundance of species. Akaike's information criterion (AIC, Akaike 1973) was used 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 and AIC were calculated using the R package (Ihaka and Gentleman 1996; R Development Core Team 2005).

Principal component analysis (PCA, Gaunch 1984) was chosen to compensate for multicollinearity and to compute relationships among species. We used standardized data, with zero mean and unit standard deviation (Legendre and Legendre 1998).

The vagility of *C. olympiae* was studied by taking into account the linear distances and the turning angles between consecutive fixes (Cain 1989). The compactness of the path was evaluated by the ''index of tortuosity''. This index is based on the ''convex hull'' of the path, which is the smallest convex polygon that contains it. To calculate the index of tortuosity of each individual we used the L/M ratio, where M is the major diameter of the polygon and L is the total path length (Fortin and Dale 2005). Differences in vagility and tortuosity were tested by three-way ANOVA, considering habitat (beech forest and alpen rose shrubbery), period of the day (night and day) and sex as factors.

Results

Eleven large ground beetle species were sampled in our study area. All species were of conservation interest because they are precinctive (or endemic) to more or less restricted geographic areas. One species was endemic to Italy (namely, *Cychrus italicus* Bonelli, 1809), two were precinctive to the Alps (*Cychrus angustatus* Hoppe,1825 and *Carabus depressus* Bonelli, 1811) and eight were endemic to more or less restricted areas of the western Alps [*C. olympiae*; *Carabus monticola* Dejean, 1826; *Carabus concolor* Fabricius, 1792; *Cychrus cordicollis* Chaudoir, 1835; *Tanythrix senilis* (Schaum, 1859); *Abax exaratus* (Dejean, 1828); *Pterostichus flavofemoratus* (Dejean, 1828); *Pterostichus spinolae* (Dejean, 1828)]. *C. olympiae* and *T. senilis*, in particular, were steno-endemites of southern slopes of Mount Rosa Alps, solely found in two and seven sites, respectively.

Three species (*A. exaratus*, *P. flavofemoratus* and *P. spinolae*) were numerically dominant (all together 5448 individuals, 88.6% of the capture), five (*C. olympiae*, *C. concolor*, *C. monticola*, *C. depressus* and *T. senilis*) intermediate (673 individuals, 11%) and three (*C. italicus*, *C. cordicollis* and *C. angustatus*) very infrequent (25 individuals, 0.4%). Sample size for *Cychrus* species was therefore not adequate and, accordingly, they were excluded from subsequent analyses.

Differences between habitat types

Forest, shrubbery and pasture plots showed significant differences in terms of species abundance and richness. Plots located in beech forests and/or alpen rose shrubberies supported the greatest ground beetle species richness and abundance, whereas those set in pastures presented the lowest values (Table 1).

This pattern may be explained by species-specific habitat preferences. Most species (seven out of eight) were more abundant in forests and/or shrubberies than in pastures. Only one (*C. concolor*) presented a reversed habit, being trapped more frequently in pastures than in the other two habitats. LSD post-hoc pair-wise tests showed that abundances in pastures were usually significantly lower than in shrubberies and/or forests (Table 1). High standard deviation values, beside explaining the lack of significance of F-values in some ANOVA tests, suggest environmental factors other than habitat control for the presence of ground beetle species (Table 1).

Effects of environmental variables

Generalized linear models suggested that habitat type was significantly related to abundances of several species ; abundances of *C. depressus*, *A. exaratus* and *C. monticola* significantly increased from open to close habitats, while abundances of *C. concolor* increased in the reverse direction (Table 2). As for the ground beetle assemblage, species abundance was positively and significantly related to habitat type (increasing from open to close habitats), while species richness was positively and significantly influenced by the density of stones (Table 2).

The first two axes of the PCA explained together 64.3% of total data variance (factor 1: 42.9%, factor 2: 21.4%). Plotting of species in the PCA ordination space confirmed differences in habitat type preferences and pointed out three different species groups, i.e. species mostly found in beech forests (*A. exaratus*, *C. depressus* and *C. monticola*), species found both in beech forests and in alpen rose shrubberies (*C. olympiae*, *P. flavofemoratus*, *P. spinolae* and *T. senilis*) and species mostly found in pastures (*C. concolor*) (Fig. 1). Stone density and proximity to roads showed very similar factor 1 loadings (−0.80 and −0.83, respectively), hence suggesting they were correlated. We hypothesized that during road construction earthmoving machines had removed and amassed stones on the side of the building roads. Some ground beetle species are known to positively select stones to shelter under them (*petrophily*). Hence, to test the hypothesis that the presence of certain

Table 1 Differences between habitats (i.e. beech forests, alpen rose shrubberies and pastures). Mean ± SD of richness, diversity and abundance of the carabid guild and abundance of each species per plot are given. Inter-habitat differences were tested with one-way ANOVA

	(1) Forest (14 plots)	(2) Shrubbery (11 plots)	(3) Pasture (9 plots)	Inter-habitat differences	Significant pairwise comparisons at $P < 0.05$
Guild					
Species richness	6.0 ± 1.3	6.3 ± 1.0	4.6 ± 1.2	$F_{(2,31)} = 6.9$**	(1) *vs* (3); (2) *vs* (3)
Abundance	183.4 ± 116.7	181.2 ± 141.3	50.9 ± 35.9	$F_{(2,31)} = 5.0$*	(1) *vs* (3); (2) *vs* (3)
Diversity	1.2 ± 0.2	1.2 ± 0.2	1.1 ± 0.3	$F_{(2,31)} = 0.7$	
Species					
Carabus concolor	0.1 ± 0.3	4.2 ± 6.0	9.0 ± 15.4	$F_{(2,31)} = 3.0$	(1) *vs* (3)
Carabus depressus	7.6 ± 9.2	1.6 ± 2.2	0.3 ± 0.5	$F_{(2,31)} = 5.0$*	(1) *vs* (2); (1) *vs* (3)
Carabus monticola	3.8 ± 3.4	1.7 ± 2.9	0.8 ± 1.0	$F_{(2,31)} = 3.8$*	(1) *vs* (3)
Carabus olympiae	1.9 ± 2.5	2.6 ± 2.5	0.3 ± 0.7	$F_{(2,31)} = 3.2$	(2) *vs* (3)
Abax exaratus	86.8 ± 71.1	20.5 ± 16.0	6.0 ± 10.5	$F_{(2,31)} = 10.1$***	(1) *vs* (2); (1) *vs* (3)
Pterostichus flavofemoratus	48.5 ± 40.1	56.3 ± 61.3	18.3 ± 15.0	$F_{(2,31)} = 2.3$	
Pterostichus spinolae	29.1 ± 20.8	85.3 ± 71.1	14.0 ± 15.2	$F_{(2,31)} = 8.2$**	(1) *vs* (2); (2) *vs* (3)
Tanythrix senilis	5.8 ± 4.8	9.1 ± 20.3	1.3 ± 3.5	$F_{(2,31)} = 1.1$	

Least-squares deviation (LSD) post-hoc tests were used for pair-wise comparisons of means, vs = versus. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. *Cychrus* species (namely *C. italicus*, *C. cordicollis* and *C. angustatus*) were inadequately sampled (14, six and five individuals, respectively) and, therefore, they are not reported here

species significantly depended on stone density, we choose plots located in the same beech wood and tested for differences between high stone density sites (adjacent to roads) and low density sites (above 20 m from roads) by means of nested ANOVA using data from individual traps (plots nested into stone density categories). We selected five high density and five low density plots, each plot containing eight traps. Results indicated that *C. depressus* and *A. exaratus* were significantly more abundant in areas with high stone densities than in areas with low stone densities; *C. monticola* and *C. olympiae* showed the same trend as well, but differences were not completely significant (Table 3).

The effect of grazing

To test the hypothesis that the ground beetle guild was affected by grazing, we choose plots located in pastures and tested for differences between high and low intensity grazing by means of nested ANOVA using data from individual traps (plots nested into grazing intensity categories). We selected four overgrazed and five undergrazed plots, each plot containing eight traps. Results showed that the ground beetle assemblage of pastures was negatively affected by grazing; in particular, the total number of individuals of the guild

Table 2 Generalized linear models of ground beetle species richness, diversity and abundance (guild) and abundance of each ground beetle forest species (species) on environmental predictors. Variables were added sequentially

Species	ß	SE	*P*
Pterostichus spinolae			
Altitude	2.90	1.15	<0.01
AIC = 179.64			
Carabus depressus			
Habitat type	0.36	0.10	<0.001
Geographical aspect	0.84	0.25	<0.01
Density of stones	0.30	0.16	N.S.
AIC = 94.46			
Abax exaratus			
Habitat type	1.35	0.25	<0.001
Density of stones	1.21	0.52	<0.05
Proximity to roads	0.34	0.39	N.S.
Geographical aspect	1.84	0.64	<0.01
AIC = 157.70			
Carabus monticola			
Proximity to roads	0.30	0.09	<0.01
Habitat type	0.19	0.07	<0.05
AIC = 75.94			
Carabus concolor			
Habitat type	-0.43	0.12	<0.01
Proximity to roads	-0.36	0.15	<0.05
AIC = 108.90			
Guild			
Abundance			
Habitat type	1.43	0.46	<0.01
Geographical aspect	3.07	1.22	<0.05
AIC = 202.19			
Richness			
Density of stones	0.13	0.06	<0.01
AIC = 23.29			

SE, standard error, N.S., not significant

dropped in the overgrazed sites, due to the significant decrease in the abundances of certain species, such as *P. flavofemoratus* and *C. monticola* (Table 4).

Movements

A total of 21 individuals of *C. olympiae* were captured and radio-tracked, nine (six males and three females) were caught in the beech forest, twelve (seven males and five females) in the alpen rose shrubbery. A total of 532 fixes (255 in the forest and 277 in the shrubbery) were collected. All animals located in the beech forest were under the leaf littery; 90% of those located in the shrubbery were hidden under alpen rose shrubs and 10% under grass. No individual abandoned its original habitat; in one instance a male of a shrubbery reached the border with the pasture and immediately turned round and went back to the shrubs.

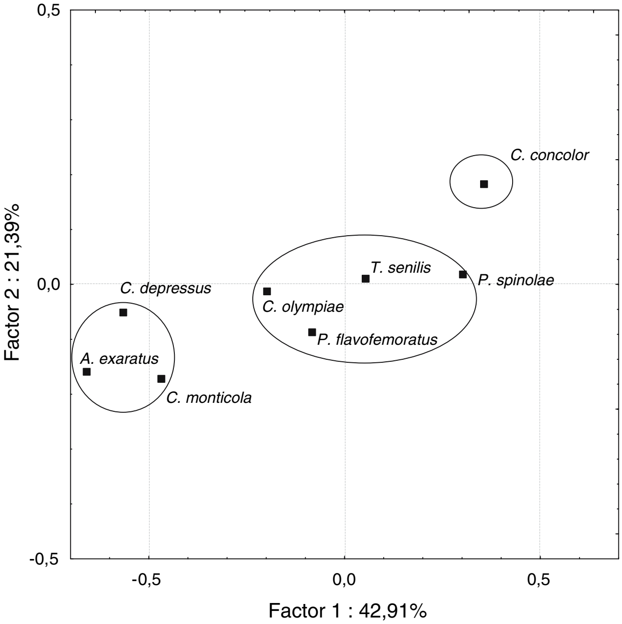

Fig. 1 Plots of ground beetle species in the PCA ordination space. Three groups of species are identified. From right to left (and from bottom to top): species mostly found in beech forests (*C. depressus*, *C. monticola* and *A. exaratus*), species found both in beech forests and alpen rose shrubberies (*C. olympiae, T. senilis, P. spinolae, P. flavofemoratus*) and species mostly found in pastures (*C. concolor*). Percentages of total variance explained by factors are given

Table 3 Differences between forest areas with high and low stone density in the neighbourhood of roads. Mean ± SD of species richness, diversity and abundance of the guild and abundance of each species per trap are given. Inter-habitat differences were tested with nested ANOVA (plots nested into stone density categories)

	Stone density categories		Differences between categories
	High (5 plot)	Low (5 plot)	
Guild			
Species richness	4.2 ± 1.8	3.2 ± 1.5	$F_{(1,8)} = 3.0$
Abundance	34.3 ± 29.0	23.7 ± 24.4	$F_{(1,8)} = 2.1$
Diversity	0.9 ± 0.4	0.9 ± 0.4	$F_{(1,8)} = 0.1$
Species			
Carabus concolor	0.0 ± 0.2	0.0 ± 0.0	$F_{(1,8)} = 1.0$
Carabus depressus	2.1 ± 2.7	0.6 ± 1.6	$F_{(1,8)} = 8.5$*
Carabus monticola	0.8 ± 1.2	0.4 ± 0.7	$F_{(1,8)} = 4.0$**
Carabus olympiae	0.5 ± 0.9	0.1 ± 0.4	$F_{(1,8)} = 3.7$**
Abax exaratus	19.9 ± 19.1	8.8 ± 10.1	$F_{(1,8)} = 7.8$*
Pterostichus flavofemoratus	6.5 ± 7.3	7.5 ± 10.5	$F_{(1,8)} = 0.0$
Pterostichus spinolae	3.5 ± 4.2	5.3 ± 6.7	$F_{(1,8)} = 0.8$
Tanythrix senilis	1.1 ± 1.8	1.1 ± 2.1	$F_{(1,8)} = 0.0$

*$P < 0.05$, **$P < 0.07$

Table 4 Differences between high and low grazing intensity pasture areas. Mean ± SD of species richness, diversity and abundance of the guild and abundance of each species per trap are given. Inter-habitat differences were tested with nested ANOVA (plots nested into grazing intensity categories)

	Grazing intensity categories		Differences between categories
	High (4 plot)	Low (5 plot)	
Guild			
Species richness	1.0 ± 1.4	1.9 ± 1.2	$F_{(1,7)} = 3.4$
Abundance	2.3 ± 4.0	8.4 ± 13.1	$F_{(1,7)} = 6.1$*
Diversity	0.6 ± 0.5	0.5 ± 0.5	$F_{(1,6)} = 0.2$
Species			
Carabus concolor	0.4 ± 1.2	1.7 ± 4.6	$F_{(1,7)} = 1.0$
Carabus depressus	0.0 ± 0.2	0.0 ± 0.2	$F_{(1,7)} = 0.0$
Carabus monticola	0.0 ± 0.0	0.2 ± 0.5	$F_{(1,7)} = 6.6$*
Carabus olympiae	0.1 ± 0.4	0.0 ± 0.0	$F_{(1,7)} = 1.3$
Abax exaratus	0.4 ± 0.8	0.9 ± 3.3	$F_{(1,7)} = 0.0$
Pterostichus flavofemoratus	0.4 ± 0.8	3.3 ± 7.5	$F_{(1,7)} = 25.7$**
Pterostichus spinolae	0.9 ± 2.2	2.1 ± 3.7	$F_{(1,7)} = 1.1$
Tanythrix senilis	0.0 ± 0.0	0.3 ± 1.4	$F_{(1,7)} = 0.8$

*$P < 0.05$, ** $P < 0.01$

Vagility was no significantly different in the two habitats, while tortuosity was significantly higher in the beech forest (Table 5). Differences between night and day and between sexes were also pointed out (see Table 5).

Discussion

Although insect biodiversity conservation may be achieved through protection of single species (Assmann and Janssen 1999), ecological realism suggests that a multiple species approach may be more profitable. This implies that theoretical methods that maximize the persistence of multiple species are developed (Cabeza and Moilanen 2003; Nicholson et al.

Table 5 Individual movement differences according to habitat (forest *vs* shrubbery), sex (male *vs* female) and period of time (day *vs* night) in *C. olympiae*. Mean ± SD of distances (in metres) and tortuosity (adimensional index) are given. Differences were tested with three-way ANOVA

Factors	Categories	Distances		Tortuosity	
Habitat	Forest	4.5 ± 6.3	$F_{(1,34)} = 0.0$	2.8 ± 1.0	$F_{(1,17)} = 5.5$*
	Shrubbery	4.1 ± 6.1		1.8 ± 0.7	
Sex	Male	5.5 ± 7.3	$F_{(1,34)} = 5.9$*	2.5 ± 1.0	$F_{(1,17)} = 5.5$*
	Female	2.2 ± 2.2		1.8 ± 0.7	
Period	Night	7.5 ± 7.3	$F_{(1,34)} = 26.0$***		
	Day	1.0 ± 1.2			

*$P < 0.05$, ***$P < 0.001$. Interactions between factors were never significant

2006) and that species assemblages that deserve high conservation priorities are properly identified in the field. We believe the guild of medium and macro-carabids of Sessera valley deserves high conservation priority for at least four considerations: (1) most species were endemic to more or less restricted zones in the Alps (the only exception was *C. italicus*, which is endemic to Italy); (2) the study area was the type locality of the endangered species *C. olympiae*, which had long been considered extinct (Sturani 1947; Malausa et al. 1983) and is now limited to just two, very small areas of western Alps; (3) two species of the genus *Cychrus* (*angustatus* and *cordicollis*), which were not uncommon until thirty years ago (Casale, personal data), were poorly sampled, suggesting very low population densities; (4) all species were brachypterous, which implies they have poor dispersion power. Moreover, recent surveys carried out in several European countries have shown that large-bodied, specialist and brachypterous ground beetles are more and more prone to extinction risk consequently the habitat transformation (Kotze and O'Hara 2003). Given these remarks, the knowledge of the effects of small-scale anthropogenic habitat heterogeneity on these species is of obvious conservation relevance.

In the Alps, the long story of pastoralism has profoundly shaped the environment because pre-existing forests were cleared over large areas to increase the availability of wide open grasslands for livestock. In our study area these intervention fragmented forests and increased habitat heterogeneity, producing an eco-mosaic made up of pastures, shrubberies and woods. Differences between habitats were apparent and showed that the local carabid guild is still dominated by forest species that seem to tolerate deforestation *where and when* shrubbery formations evolve after tree-cutting. Forest management (clear-cutting and selection cutting) is known to influence carabid assemblages (Brouat et al. 2004; du Bus de Warnaffe and Dufrêne 2004; Lemieux and Lindgren 2004; Huber and Baumgarten 2005; Ulyshen et al. 2006). In Sessera valley beech forests are poorly managed and this suggests that forest patches may retain environmental conditions which are suitable for ground beetle forest species. Pastures represent a detrimental habitat loss for ground beetle forest species and the impact of grazing cattle may be detrimental as well. The effects of grazing ungulates on ground-dwelling carabid assemblages has been documented in several studies (Petit and Usher 1998; Melis et al. 2006). Our results confirmed the negative effect of grazing on carabid assemblages of pastures. Moreover, to make things worst, it should be noted that in the neighbourhood of the study area, parts of the original beech forest have been cleared to construct ski-pistes, which are known to exert a negative effect on forest bird diversity (Laiolo and Rolando 2005). Preliminary data suggest ski-runs may also threaten forest ground beetle diversity.

Roads are anthropogenic elements which may be potentially detrimental to biodiversity conservation. 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 Vermeulen 2005). Large roads are also known to produce habitat fragmentation leading to significant intraspecific genetic differentiation (Keller et al. 2004). Our study area was crossed from narrow mountain (not asphalted) roads which were forbidden to private vehicles and mostly used by shepherds to drive cattle to pastures. These roads were not avoided by ground beetles, which were often encountered there during radio-tracking bouts at night. Densities of some forest ground beetle species significantly peaked on road sides because of the large amount of stones amassed there during road construction. These results clearly suggest that narrow country roads used as foot-paths are not unfavourable to ground beetles; on the contrary, they may be beneficial to the petrophilous species. Beneficial changes in ground beetle assemblages have also been detected in farming systems bordered by complex or simple roadside vegetation

(Varchola and Dunn 1999). It may be therefore suggested that in agro-pastoral systems roadside environmental elements should be attentively considered to distinguish negative from positive effects on local biodiversity.

Radiotracking of the priority species *C. olympiae* was useful to point out finer behavioural mechanisms which underline species' reactions to man-induced ecological changes. This species seems to be able to perceive fine environmental characteristics to select the appropriate habitat (namely beech woods and alpen rose shrubberies), as anecdotally confirmed by the immediate turning round of a tagged male which had reached the border between the shrubbery and the pasture. The vagility of radio-tagged individuals were not different in the two habitats considered; however, tortuosity indices were significantly higher in beech forests than in alpen rose shrubberies. These results suggest that, albeit both habitats were frequented and actively explored, they are not completely equivalent. Beech forest might be the preferred habitat, on the assumption that in favoured habitats movements will have greater tortuosity, with more frequent and tighter turns, leading to less net displacement and greater residence time in those habitats (Turchin 1998). It can also be considered that almost all individuals wandering in shrubberies were found buried under alpen rose shrubs, which are likely used as refuge sites (to escape from predators and/or from high temperatures); it may therefore assumed that in this habitat type movements are bound by the spatial distribution of shrubs, which imposes a limit on path tortuosity. Hence, if shrubs are thinned out (through cattle grazing, for instance), conservation of this species may be threatened.

Our findings indicate that local ground beetle species diversity depends on small-scale anthropogenic variables (namely, habitat type, stone density and grazing intensity), and that habitat modifications (namely, from forest to shrubbery) may significantly affect species movements. They also suggest that local biodiversity may be preserved if anthropogenic disturbance is low. In our study area, in particular: (i) forests clearing may be tolerated, on condition that alpen rose shrubbery formations remain or evolve after tree-cutting; (ii) pastoral activities may be tolerated as well, on condition that existing pasture patches are not enlarged and that grazing intensity is kept low; and (iii) construction of agro-pastoral roads may even be beneficial (at least to petrophilous species), on condition that they are built by amassing stones roadside and that, after construction, heavy vehicular traffic is forbidden.

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