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Ski-pistes are ecological barriers to forest small mammals

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Abstract From the beginning of the last century, the expansion of the ski industry has significantly altered Alpine environments.

The aim of this research was to study the impacts of forest ski-pistes on small mammals by assessing (i) whether ski-pistes were used or avoided and (ii) whether they acted as ecological barriers to local movements.

Two ski-developed valleys of the Western Italian Alps were considered. Most of the fieldwork occurred in the Sessera Valley (Piedmont), a minor part was carried out in the Ayas valley (Aosta Valley).

In the main study site three capture-mark-recapture studies on core species were carried out to assess habitat use (one study) and the capability of crossing ski-pistes (two studies: spontaneous crossing and individual translocation). Two radiotracking surveys of the most vagile species, the fat dormouse, were carried out to locate home ranges and resting sites in relation to ski-pistes.

In the habitat use experiment, virtually all individuals (245 out of 249) were captured outside the ski-piste. In the spontaneous crossing test, recaptures of marked individuals showed they moved on one side of the ski-piste only, and never crossed it. However, in translocation experiments, 18.6% of translocated individuals were able to cross the ski-piste and come back to the original forest patch.

Fat dormice maintained home ranges on one side of the ski-piste and they never crossed it. Resting sites were mostly underground, between rocks, boulders and in rocky crevices, never in the ski-piste.

Our study clearly suggests that forest ski-pistes represent a habitat loss and are ecological, semi-permeable barriers to small mammals. To mitigate habitat loss and make movements between forest patches easier, a possible management intervention could be maintaining a partial shrub cover or adding woody debris, both relatively easy methods for ski areas to implement in order to maintain small mammal communities.

Keywords Alps, micromammals, dispersal barrier, habitat loss, habitat fragmentation, translocation experiment

Introduction

Mountain ecosystems merit high conservation status because of the often rare and/or range-restricted organisms that they house (Martin 2001) and for the presence of habitats that may provide the last refugia for many endangered species of plants and animals (Tonge 2007). The Alps represent an important biodiversity hot spot in Europe, due to an impressive variety of habitats and climatic conditions along reduced spatial scales (Chemini and Rizzoli 2003). In the last few decades, however, changes in human populations, and in agricultural and zootechnical production methods have led to substantial changes in land-use systems, including both intensification in some areas and abandonment of traditional practices in others.

Tourism can be an important means to preserve human mountain communities, bringing revenue and jobs. The European Alps are the most intensely used mountain region in the world and rank as the second largest tourist destination in the world after the Mediterranean coast. International visitors to the

region are estimated to total approximately 30 million people annually, a little less than 4% of the world's total tourist presence and almost 7% of the European presence (CIPRA 2010). This enormous mass of tourists benefits local communities financially, but also may have strong impacts on ecosystems and species, mainly due to the construction of new buildings, access roads and other human installations (Tonge 2007). Touristic areas are distributed unevenly across the Alps and next to sites that maintain a high level of wilderness, thus these are localities that are increasingly impacted by development. Winter sports have a prominent role in human-induced impacts because of the large scale of changes they cause at the landscape level (Laiolo and Rolando 2005). Since the beginning of the 20th century, development of ski areas has severely disturbed the environment in the Alps. In particular, the establishment of ski-pistes for downhill skiing impacts these ecosystems across an elevational range that touches the montane and alpine belt (forest and treeless zones, respectively). During ski-piste construction, pastures or forest tracts are clear-cut (Wipf et al. 2005) and soils are severely affected by machine-grading (Delgado et al. 2007).

Linear barriers and linear clearings are widespread forms of landscape modification that could have an array of deleterious effects on wildlife (Laurance et al. 2009). These include habitat loss and fragmentation and the change of animal's behaviour related to the presence of the barrier or the open space instead of a closed habitat (Trombulack and Frissel 2000). The result is a decrease of habitat suitability and connectivity for many species, which in turn influence the pattern of animals' movement and could lead to population isolation and extinction. Ski-pistes construction leads to habitat destruction and creates open spaces in otherwise contiguous forests, with effects that are probably similar to other linear clearings. However it must be considered that ski-pistes, unlike other linear clearings (e.g. ski-lift, power lines), are managed every year after the ski season. In fact clearance and ground-leveling in summer produce further damage to vegetation and soil (Titus and Tsuyuzaki 1999; Barni et al. 2007).

The effects of ski-piste development on animals has received little attention apart from research on birds

(Laiolo and Rolando 2005; Arlettaz et al. 2007; Rolando et al. 2007; Thiel et al. 2008), ground dwelling arthropods (Negro et al. 2009; 2010), and small mammals. Published studies on small mammals have included the short-term effects of ski-pistes development on the patterns of population density and survival (Hadley and Wilson 2004a; 2004b) and the effect of reduction in subniveal space, which is critical to over-winter survival (Sanecki et al. 2006). Studies on the barrier effect of ski-pistes on terrestrial species are still lacking.

Our research aim was to focus on the impact of forest ski-pistes by assessing (i) whether ski-pistes were used or avoided (thus providing evidence of habitat loss) by small mammals, and (ii) whether they acted as ecological barriers to local movements.

A mix of five experiments and observational studies were carried out in total. Three capture-mark-recapture studies on more abundant species (core species) were set to assess habitat use (one study) and capability of crossing ski-pistes (two studies: spontaneous crossing and individual translocation). Two radiotracking surveys of the most vagile species, the fat dormouse (*Glis glis*), were carried out to locate home ranges and resting sites (i.e. sites where animals take shelter both to rest by day and to nest) in relation to ski-pistes.

As far as we know, this is the first study specifically devoted to assess whether ski-pistes represent habitat loss and ecological barriers to small forest mammals.

Methods

Study area

Two ski-developed valleys of the Western Italian Alps were considered. Most of the fieldwork occurred in the Sessera Valley (45°40'16"N; 8°05'07"E, Biella province, Piedmont), which is hereinafter indicated as

the main study area (Fig. 1). Annual rainfall ranges from 1,700 to 1,800 mm, with a peak in spring and autumn and a minimum in summer and winter. Snow cover is present for 4-5 months from November to March. Mean temperature is 15 °C in summer (July) and -2 °C in winter (January) (IPLA 2003).

The study site (about 37 ha, confined between 1,350 and 1,450 m a.s.l.) is characterized mainly by beech *Fagus sylvatica* forests (i.e., the Luzulo- Fagetum phytosociological association). Small patches are also covered by shrubs (alpen rose *Rhododendron ferrugineum* and bilberry *Vaccinium myrtillus*) and pastures dominated by graminaceous plants. The site is confined within a private protected area (Oasi Zegna) and has been classified as a Site of Community Importance (S.C.I.), with the main conservation aim of protecting *Carabus olympiae*, one of the most endangered ground beetle species in Europe (Negro et al. 2008).

Despite the conservation importance of the area, the impact of human activities has increased in the last fifty years, mainly from development of a winter sports resort. The construction of ski facilities has significantly changed the landscape. The survey area is located within a small ski-district (Bielmonte), with 11 ski-pistes (total length equal to 18 km) and 10 ski-lifts (www.oasizegna.com). We considered ski-piste crossing beech forests, which were 83.2 m \pm 8.3 wide (50 measures) with a mean slope of 16.4° \pm 5.7 (67 measures). Means are always \pm SD.

A minor part of the fieldwork was carried out in the Ayas valley (45°48'52"N; 7°40'36"E, Aosta province, Aosta Valley). Here the study site (about 30.31 ha confined between 1,938 and 2,078 m a.s.l.) is characterized by coniferous forests (larch *Larix decidua* and Norway spruce *Picea abies*) with sparse understory mainly composed of juniper *Juniperus communis*, alpenrose *Rhododendron ferrugineum* and bilberry *Vaccinium myrtillus*. The survey area is located within a large ski-district (Monte Rosa ski-district), with 67 ski-pistes (total length equal to 180 km) and 38 ski-lifts (www.monterosa-ski.com). We considered ski-pistes crossing coniferous forests, which were 37.08 m \pm 10.9 wide (50 measures) with a mean slope of 18.4° \pm 6.0 (60 measures).

Species considered

Five small mammal species were found altogether in the main study area. Two species (the common dormouse *Muscardinus avellanarius* and the pygmy shrew *Sorex minutus*) were poorly sampled and were thus considered in the habitat use test only. The other three species (the fat dormouse *Glis glis*, the bank vole *Myodes glareolus* and the yellow-necked mouse *Apodemus flavicollis*) were more abundant and considered core species (*sensu* Magurran 2004); they were considered in habitat use, spontaneous crossing and translocation experiments. The fat dormouse was also used in radiotracking surveys to describe home ranges and selection of resting sites. Dormice are nocturnal and rest during the day. We did not detect any movements of dormice during the day (pers. obs.) and thus assumed that all diurnal fixes were resting sites, following Shibata et al. (2004). Sampling was conducted for three years (2008-2010), with the lowest capture rates in 2009 and the highest in 2010. Capture-mark-recapture experiments on core species were not carried out in 2009 because of insufficient captures. In the second study area (Ayas valley), in the year 2007, we sampled only the species bank vole (*Myodes glareolus*).

Field methods

Habitat use. To determine if species used or avoided ski-pistes, animals were captured during three periods: July 2008 (18 days), July 2010 (15 days) and September 2010 (10 days). Sixty Sherman live traps were spaced at 8-m apart in three parallel transects (Fig. 1): 20 were positioned in the beech forest (transect A), 20 in the ski-piste (transect C) and 20 at the edge between the two habitats (transect B).

Traps were baited with apple and hazelnut cream and filled with cotton material for thermal insulation. Each day, traps were set in the evening and inspected in the morning. Trapped animals were lightly anaesthetized with ethyl ether and individually marked with fur bleaching and fur clipping.

In the second study area one period was considered (July 2007, 10 days), the experimental design being the same as in the main study area.

Habitat use for each species was evaluated using χ^2 -tests by comparing the observed number of individuals trapped in the three habitats (beech forest, edge and ski-piste) with the expected number assumed to be no preference among habitats. For each individual we only considered the first capture.

Spontaneous crossing. To evaluate the tendency to spontaneously cross ski-pistes, individuals of the three core species were captured for ten days along five transects, four placed on the two sides of the piste and one in the middle. Transects A and E were set in beech forest; B and D were set along the two edges and transect C in the middle of the ski-piste (Fig.1).

The five transects were spaced at 40 m apart. This distance is normally travelled by all the three core species during one night (Szacki and Liro 1991; Kotzageorgis and Mason 1996; Jurczynsyn 2006).

All individuals caught were uniquely marked with ear-clipping and released at the point of capture to assess the tendency of spontaneous crossing (from right to left or *vice versa*). The experiment was carried out in September 2010, when a particularly high population density of the three core species was detected. We assumed that both the high density and additional tendency of young to disperse would have enhanced the possibilities of spontaneous crossing.

Translocation. The motivation for animals to traverse a barrier may increase during particular time periods, such as mating and dispersal (McGregor et al. 2008). To simulate such high-motivation situations, we performed translocation experiments that provided information on whether ski-pistes were a barrier to these species, following an approach similar to McGregor et al. (2008) who examined

the effect of roads. Animals trapped in the forest on one side of the ski-piste during the habitat selection study (in July 2008 and July 2010) in transects A or B (Fig.1) were released on the other side of the ski-piste. Recaptures of marked animals on the captured side were recorded as successful returns. We considered a return index for each species as the percentage of individuals that successfully crossed the ski-piste to the total number of translocated individuals.

Radiotracking. The fat dormouse, the species with the largest home range and the greatest dispersal ability, was chosen to study home ranges and to assess whether the ski-piste was included within them. We used radio transmitters TW4 (3.28 g, Biotrack Ltd, Wareham, England) with specific individual frequencies. Only animals with body weight ≥ 100 g were fitted with collars, so that the transmitter package was never heavier than 4% of their body mass. After radio-tagging, fat dormice were kept for one hour in a dark box before release at the capture site. In beech forest, the transmitter range was usually less than 300 m, depending on the roughness of the terrain. Under field conditions the longest tag battery life span was three months.

Animals were tracked every day, from 18:00 to 02:00 or from 24:00 to 06:00 alternately. At the beginning of the radiotracking session and repeatedly during the night, we scanned the two sides of the ski-piste to search for the animals. We then continued locating the animals with the homing-in technique (Kenward 2001), using a TRX 1000S (Wildlife Materials, Illinois USA) receiver and a hand-held Yagi directional antenna. During the day we returned to the study area to locate the daytime resting sites (see the subsequent experiment). The position was determined using a Garmin GPS. At the end of the experimental period, if possible, radio-tagged individuals were caught to retrieve transmitters and subsequently released. Total home range sizes were calculated using the minimum convex polygon method (MCP, including 100% of the point-fixes) by means of Hawth's Analysis Tools extension for ESRI's ArcGIS 9.3 (Beyer 2004; ESRI 2009).

Selection of resting sites. To test the prediction that fat dormouse selected resting sites characterized by precise environmental factors, and to assess subsequently whether the ski-piste was suitable for resting, resting sites located through radiotelemetry were compared with random sites in the same forest. For every resting site, we selected two random points within the overall MCP (Bertolino and Cordero di Montezemolo 2007). Points were randomly chosen drawing the coordinates by means of Hawth's Analysis Tools extension for ESRI's ArcGIS 9.3 (Beyer 2004; ESRI 2009). Habitat structure characteristics of each point (i.e. both resting and random sites) were recorded in circular areas of 20 m radius. We measured herb (i.e. grasses and herbaceous plants in the ground layer), litter, soil, rock, shrub and dead wood cover, canopy closure (estimated by eye), and number of stumps (further details on methods are given in Bertolino 2007; Bertolino and Cordero di Montezemolo 2007). Variables were checked for normality using the Kolmogorov-Smirnov test and were transformed as appropriate: percentages were arcsine square root transformed, counts were square root transformed after adding 0.5 (Sokal and Rohlf 1995). Any variable in resting sites and random points were compared using *t*-test.

Principal component analysis (PCA; Gaunch 1984) was chosen to minimize the effects of multicollinearity and to reveal patterns in the data for habitat structure (i.e. the eight variables listed above) using standardized data (zero mean and unit standard deviation; Legendre and Legendre 1998). We used generalized linear models (GLM) to test for the effects of habitat structure (three scores of PCA) on the likelihood of the presence of a resting point. Akaike's information criterion (AIC; Akaike 1973) was used to select the most appropriate models, i.e. the best fit to the available data set. AIC is based on the principle of parsimony and helps to identify the model that accounts for the most variation with the fewest variables; the model that best explains the data is that with the lowest AIC. All tests were performed using STATISTICA 8.0 package (StatSoft Italia srl 2007). Considering that n/K , where n is the sample size and K is the number of parameters, was less than 40 when all parameters were included in the model. AIC_c rather than AIC was therefore used as this is preferred when K is large relative to sample

size (Burnham and Anderson, 1998). The AIC_c value was calculated using the $-\log$ -likelihood value for each model (Greaves et al. 2006). The lower the AIC_c value the better the model. The models were ranked by rescaling the AIC_c values such that the model with the minimum AIC_c has a value of 0. The larger Δ_i the less plausible the fitted model i as being the best approximating model in the candidate set (Anderson et al. 2000). The likelihood of the model given the data was calculated as Akaike weights W_i . These can be interpreted as approximate probabilities that model i is the best model in the set of models considered (Greaves et al. 2006).

Results

Habitat use

A total of 249 small mammals were captured in 2,580 trap nights in the main study area: 156 yellow-necked mice, 42 bank voles, 43 fat dormice, 5 common dormice, and 3 pygmy shrews. With the exception of two bank voles and two yellow-necked mice, all other animals were captured outside the ski-piste. Fat dormice were mostly captured in beech forest, whereas yellow-necked mice and bank voles were captured both in forest and at the edge between forest and ski-piste. All data pooled, observed trapping frequencies in the three adjacent habitats were significantly different from expected for all species [yellow-necked mouse ($\chi^2_{(2)} = 74.00$; $P < 0.001$), bank vole ($\chi^2_{(2)} = 31.00$; $P < 0.001$) and fat dormouse ($\chi^2_{(2)} = 50.84$; $P < 0.001$)]. Detailed results, divided according to the three periods considered, are shown in Fig. 2.

A total of 15 bank voles were captured in 420 trap nights in the second study area. All were captured outside the ski-piste, both in coniferous forest and at the edge between forest and ski-piste. ($\chi^2_{(2)} = 12.40$; $P < 0.01$).

Spontaneous crossing

A total of 90 individuals were trapped in 1,000 trap nights: 44 in beech forest transects, 44 along edges and 2 in the middle of the ski-piste (Fig. 3). The recapture ratio (numbers of recapture events / numbers

of individuals captured) was higher for fat dormouse (2.0) followed by yellow-necked mouse (1.4) and bank vole (0.5). Marked individuals moved along the same transect in the forest or at the edge, or between the two transects on the same side of the piste, but they never spontaneously crossed the ski-run (Fig. 4).

Translocation

A total of 33 out of 177 small mammals translocated to the other side of the ski-piste (i.e. 18.6%), were recaptured after they crossed back to the ski-piste (Table 1). The return index was lower for yellow-necked mouse (average between two years = 14.7%) and higher for bank vole (20.0%) and fat dormouse (36.7%).

Radiotracking

Thirteen fat dormice were radiotracked in total: three in 2009 (one male and two females) and ten in 2010 (seven males and three females). Three individuals, that lost the collar a few days after its application, were poorly radiotracked (< 20 fixes), whereas the other 10 were radiotracked enough to fully describe their ranges (as tested by incremental-area curves) (Fig. 5). Individuals were radiotracked for a mean of 21.7 ± 12.2 days/individual (range: 3-49), corresponding to a mean of 31.0 ± 15.6 fixes/individual (range: 4-49). A total of 375 fixes (220 by night and 155 by day) were collected. Mean home range sizes (MPC 100%) were significantly larger ($t_{(11)} = -2.29$; $P = 0.04$) in males (3.7 ± 1.9 ha) than in females (1.5 ± 1.2 ha). Individual home ranges never included the ski-piste, nor did individuals ever

cross the piste (Fig. 5). On six occasions a fat dormouse reached the edge of the ski-piste during the night and immediately turned back to the beech forest without crossing the ski-piste (Fig. 5).

Selection of resting sites

Nineteen resting sites were located by radiotracking, all in the beech forest: eighteen were located underground, mostly between rocks and boulders and in rocky crevices, while one was situated inside a birch tree hollow (Fig. 5). Univariate comparisons of variables of resting sites versus random points (t-tests), indicated significant differences for five habitat variables (Table 2). The sites selected for resting were characterized by a higher herb, rock and shrub cover, and lower litter cover and number of stumps.

The first three principal components (PC1, PC2, PC3) accounted for 69.9% of the total variation in the habitat structure matrix, with eigenvalues > 1 (Table 3). The percentage of herb and rock cover provided the major positive loading and the percentage of litter, dead wood and canopy cover the major negative loading on PC1. The number of stumps and the soil cover showed respectively the major negative loading on PC2 and PC3 (Table 3).

The best models (i.e. that minimize AIC_c) are shown in Figure 4. The parameter considered (presence of resting site) was best modeled by a combination of factors that included PC1 and PC3.

Discussion

In this study, we have demonstrated that the interruption in the continuity of the forest cover caused by ski-pistes can severely affect the ecology of small mammals in two ways. First, these anthropogenic linear open habitat elements are usually avoided by small forest mammals, thus representing a typical case of habitat loss to this fauna. Second, ski-pistes cutting through forest may also act as ecological barriers that partially or totally prevent individuals from moving between adjacent forest patches.

Forest ski-pistes as habitat loss

Habitat loss and fragmentation may be closely inter-related and their effects difficult to disentangle (Hanski 1999; Mortelliti et al. 2010). The impact connected to habitat loss and fragmentation has been particularly severe in lowland forests that have experienced a long history of anthropogenic disturbance (Hanson 1983; Gurdebeke et al. 2003; Cushman and McGargal 2003). It has been shown, for instance, that anthropogenic forest fragmentation might cause local or regional extinction of the most forest-dependent animal species, as a consequence of increased predation rates and brood parasitism at the forest edge (Faaborg et al. 1995; Kurosawa and Askins 2003), inhibition of dispersal and reduction in home range size (Forman 1997) and intensification of human disturbance (McGarigal et al. 2001). Removal of forest cover is therefore rightly perceived by biologists as a serious risk to the environment in general and to forest small mammals in particular.

At least three studies (i.e. habitat use, radiotracking and selection of resting sites) conformed to the hypothesis that the construction of ski-pistes creates an unsuitable habitat for small mammals. In the habitat use study as expected, virtually all individuals (260 out of 264 in the main area and all individual in the second area) were captured outside ski-pistes. This suggests that ski-tracks are selectively avoided by forest small mammals, in keeping with previous findings, derived from occasional captures in

invertebrate pitfall traps located in other two different ski-districts of Aosta valley (Negro et al. 2009). Fat dormouse was mostly captured in forest, whereas yellow-necked mouse and bank voles were captured both in forest and at the edge between forest and ski-piste. This habitat use pattern is in line with the data reported in the literature for these three species. Fat dormouse prefers dense forests with well-connected tree canopies and dense understory (Milazzo et al. 2003; Kryštufek 2010). It is also found in forest edge with dense herb and shrub strata (Gaisler et al. 1977). Yellow-necked mouse is restricted in most of its range to mature forests, both coniferous and deciduous, with a preference for the latter (Wolk and Wolk 1982; Marsh et al. 2001). The species prefers mature forests, avoiding young woods and recently coppiced areas (Capizzi and Luiselli 1996). Bank voles occurs in all types of forests, from plains to mountains, but prefers areas with high structural complexity and good presence of shrubs, grass and rocky cover (Gurnell 1985; Mazurkiewicz 1994). In the Alps, its relative abundance with respect to yellow-necked mouse increases with altitude from deciduous to coniferous forests.

The radiotracking survey of fat dormouse showed that individual home ranges did not include the ski-piste and that the animals never crossed it. This indicates that the anthropogenic open habitat was perceived as unsuitable by this species. Radiotracking also allowed us to locate resting sites, which were mostly underground, between rocks, boulders and in rocky crevices. Variables that best discriminated resting sites from random points were rock and shrub cover, both being higher in resting sites (by 36.7% and 7.0%, respectively) than in random sites (6.4% and 0%). Ski-pistes in our main study area were never used for resting by fat dormouse, probably because it lacked environmental characteristics selected by the species. This is due to the modern techniques of ski-piste construction, which rely on bulldozers and power shovels to remove shrubs, rocks and soil.

Forest ski-pistes as ecological barriers

While several studies have investigated the effect of forest fragmentation produced by roads and other linear infrastructures (McGregor et al. 2008; Laurance et al. 2009), none have previously considered ski-pistes as possible barriers to small mammal movements. At least three tests (i.e. spontaneous crossing, translocation and radiotracking of the fat dormouse) conformed to the hypothesis that forest ski-pistes may act as ecological barriers for small mammals of alpine forests.

The spontaneous crossing experiment was carried out in September, which is a typical dispersal period for several small mammal species. The end of summer is the period of juvenile dispersal for fat dormouse (Bieber 1995; Kryštufek 2010). Yellow-necked mouse has two dispersal periods in spring-summer and autumn (Gliwicz 1988), whereas bank vole disperses throughout the year, with a post-reproduction dispersal dominated by young (Gliwicz 1988; Shore and Hare 2008). These phenological data are in keeping with our results. Despite the fact that high density and the greater tendency of young to disperse had likely enhanced the possibilities of spontaneous crossing, recaptures of the marked individuals showed that they moved on one side of the ski-piste only, and never crossed it. Similarly, radiotracking showed that fat dormouse maintained home ranges on one side of the ski-piste. In a few instances, individuals arrived at the edge of the piste, but they never crossed it. These results suggest that ski-pistes are not spontaneously crossed by small mammals. However, in translocation experiments (which simulated situations in which individuals were highly motivated to cross a barrier), 18.6% of translocated individuals of the three species were able to cross the ski-piste, returning to the area where they were captured.

Our study clearly suggests that forest ski-pistes act as ecological, semi-permeable barriers. The degree of permeability relies on several factors. One factor is likely to be the width of the ski-piste. The studied ski-piste (average width 83.2 ± 8.3 m) was in fact considerably wide. Another factor is the lack of shelter in the ski-pistes. Dense shrubby vegetation provides protection for many small mammals and is an

important factor in avoiding avian predators (King 1985). This anti-predator adaptation explains why forest small mammals use or cross open areas only in the presence of woody vegetation and rocky cover. The importance of refuges was also underlined by Hadley and Wilson (2004b), who state the possibility that clearing created by ski-run development may present a formidable obstacle to voles, at least when wood debris (i.e. shelters) are not retained in the ski-piste.

Conclusions and conservation implications

Linear infrastructures and other human interventions that interrupt the continuity of forests may reduce habitat availability and increase forest patch isolation. While the effects on wildlife related to road and railway developments have been widely studied since the 1970s (Benítez-López et al. 2010), those related to ski-pistes have been completely neglected so far. Considering that in the European Alps alone thousands of kilometers of ski-pistes have already been constructed (Rolando et al. 2007), the fragmentation potentially produced by these linear elements should be assessed and mitigation strategies should be implemented.

Our research demonstrated that ski-pistes are unsuitable habitats for forest small mammals, acting as ecological barriers that prevent or limit animal movements. This is probably related to the modern techniques of ski-piste construction and maintenance that aims not only to remove trees and shrubs, but also rocks and part of the soil. The complete absence of any cover along ski-pistes may limit the dispersal ability of small mammals due to the lack of shelter. To make movements between forest patches easier, a possible management intervention could be enhancing a partial shrub colonization of ski-pistes. It has been demonstrated that the presence of shrubs facilitates the movements of small mammals (Alibhai and Gipps 1991; Tattersall et al. 2002). It is worth mentioning that in summer 2007, during a preliminary

radiotracking test in our main study area, one yellow-necked mouse was found on a ski-piste that had been abandoned more than 10 years earlier and was colonized by a dense alpen rose and bilberry shrubbery and sparse birches. Shrub cover may also increase the use of the ski-piste by ground-dwelling arthropods, which use woody vegetation as shelter and protection from predators (Negro et al. 2007; 2008). Hadley and Wilson (2004a) showed that southern red-backed vole (*Myodes gapperi*) populations declined in areas of new ski-piste creation. These authors, however, were able to maintain the presence of the species in an experimental ski-piste where woody debris was added, suggesting that voles not only can persist in, but also can travel across, ski-pistes when woody debris is present.

Maintaining a shrub cover and/or adding woody debris may be a relatively easy method for ski areas to maintain both existing small mammal communities and ground-dwelling arthropods. If shrubs are not too high, they will be covered by snow during winter not interfering with skiing. Therefore, after tree clearing, only the roughest ground surfaces should be leveled, in order to preserve as much natural vegetation as possible. If necessary, woody debris coming from tree clearing should be placed in the ski-piste. This will increase the suitability of the ski-pistes for the terrestrial fauna, reducing the impacts on forest species. Furthermore, this intervention will increase the permeability of the pistes to small mammals and other species, avoiding the barrier effect and the creation of isolated forest patches where local populations might be more prone to extinction.

Any management for mitigation aimed at reducing the barrier effects of ski-pistes should be planned at the district level with the development of site-specific management plans. Specific measures should include an assessment of ski-piste width across the whole local forest and slope system to assess whether some areas could be sufficiently narrowed to allow dispersal and 'spontaneous movements' across open habitats by animals. This should then be followed up with suggested measures to narrow gaps or to adopt a stepping stone approach using wooded debris or partial shrub colonization.

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Fig. 1 Illustration of the study site (3) located in the Sessera Valley (2), North-Western Italian Alps (Biella province, Piedmont) (1). Transects, with twenty Sherman live-traps each, are indicated with capital letters. Transects A and E were set in the beech forest; transects B and D at the edge between the forest and the ski-piste; transect C was set in the middle of the ski-piste.

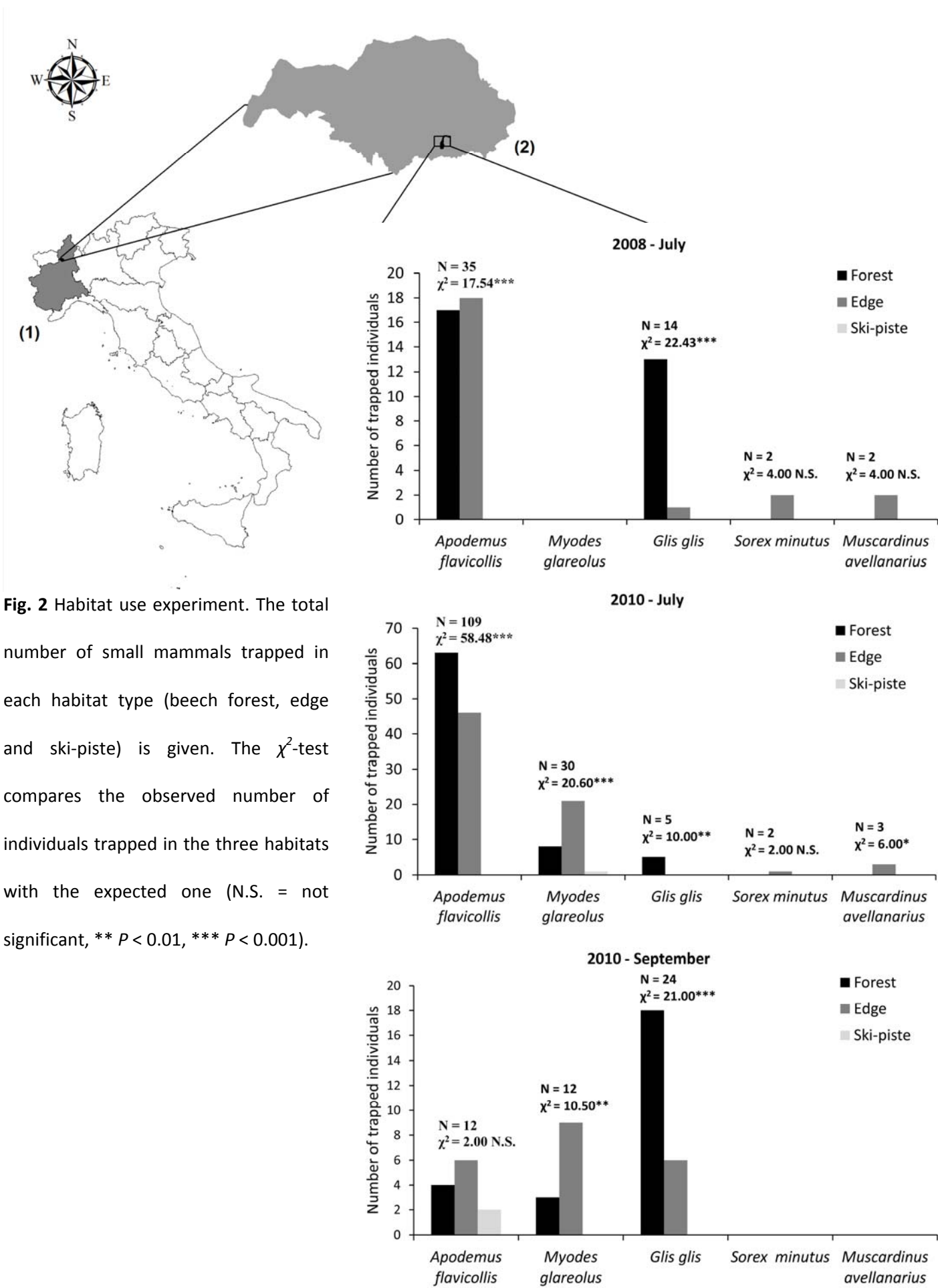


Fig. 2 Habitat use experiment. The total number of small mammals trapped in each habitat type (beech forest, edge and ski-piste) is given. The χ^2 -test compares the observed number of individuals trapped in the three habitats with the expected one (N.S. = not significant, ** $P < 0.01$, *** $P < 0.001$).

Fig. 3 Spontaneous crossing experiment. Number of individuals trapped and recaptured in the five transects. No individuals crossed the ski-piste in any of the two directions.

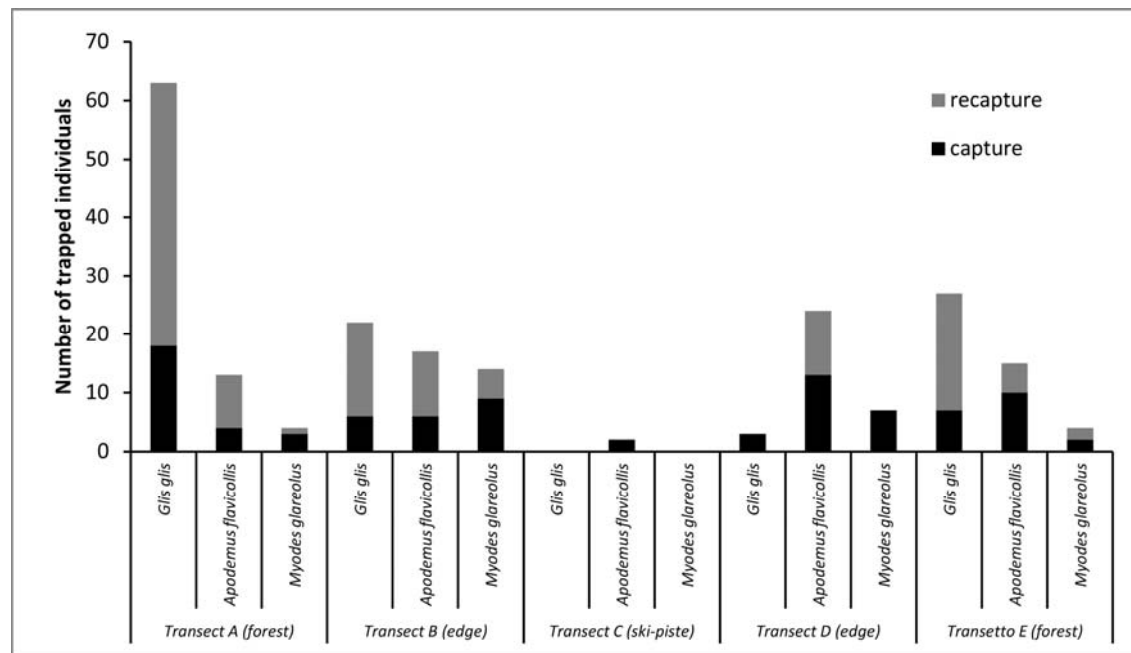


Fig. 4 Spontaneous crossing experiments. Recaptures examples of seven fat dormice during the natural crossing experiment. Transects A and E were set in the beech forest; transects B and D at the edge

between the forest and the ski-piste; transect C was set in the middle of the ski-piste. Fat dormice moved on the same side of the ski-piste, between the transect in beech forest and that at the edge (above) or along the same transect (below). They never crossed the ski-piste. Line colour is used to visually distinguish individual dormice. Numbers indicate the chronological sequence of re-capture.

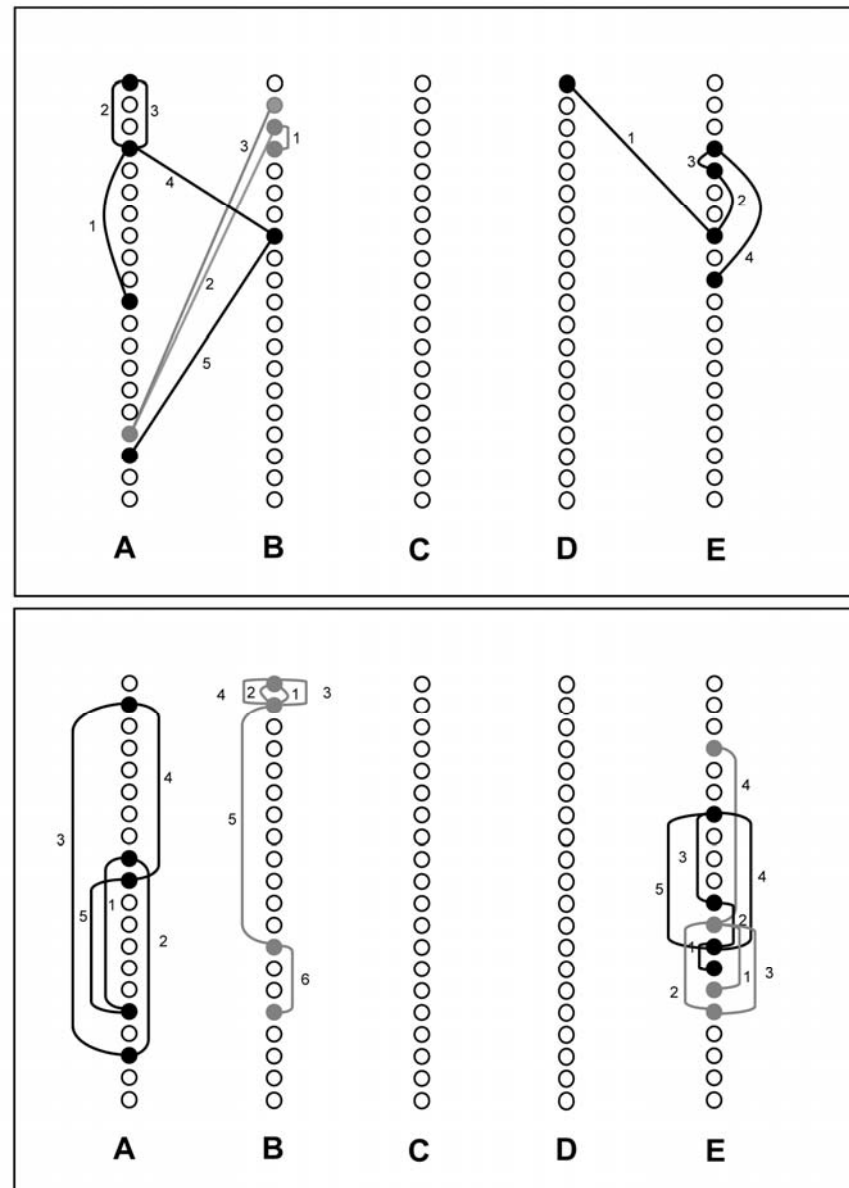
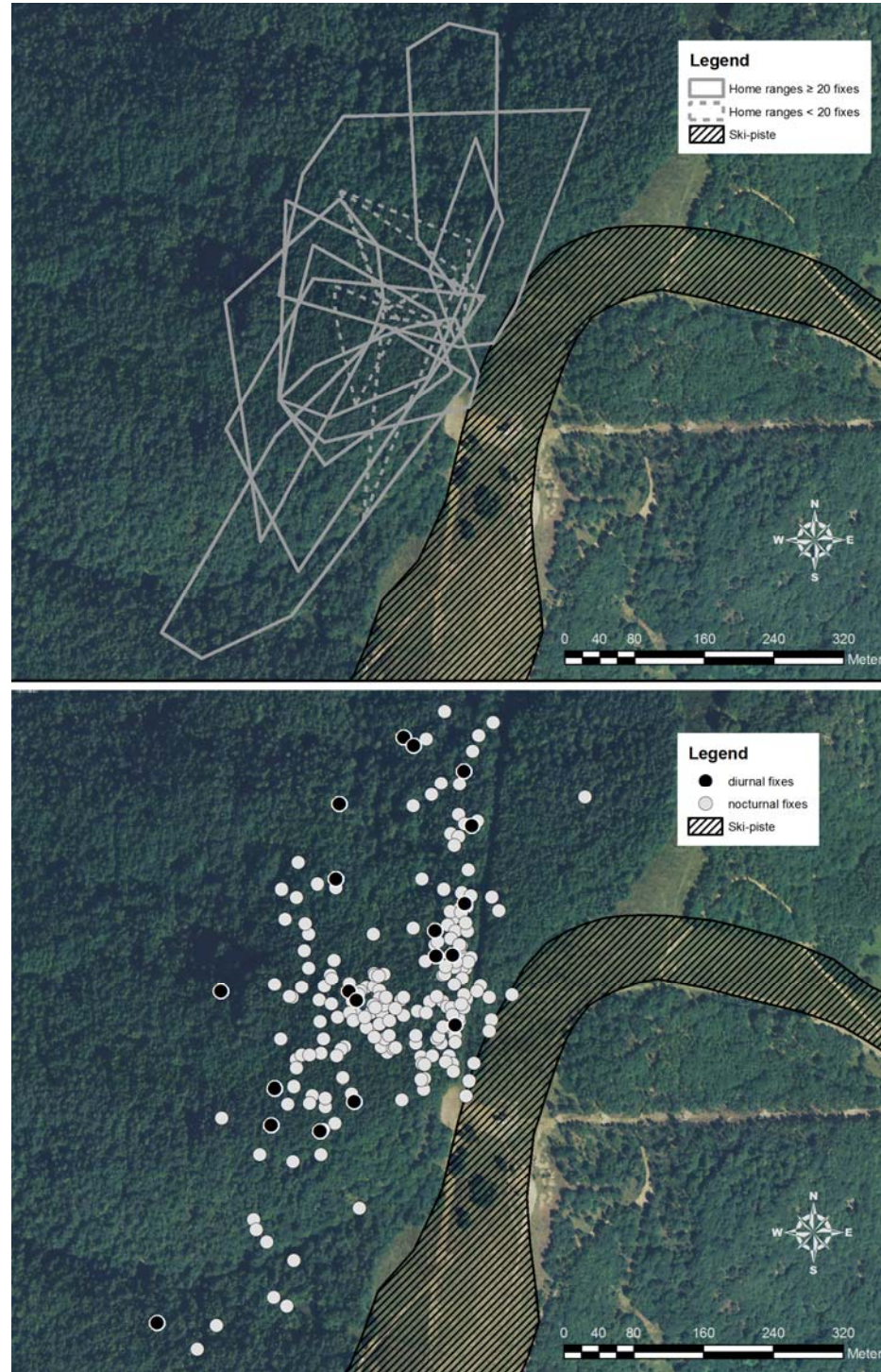


Fig. 5 Radiotracking experiment. Above: home ranges (MPC 100%) of 13 fat dormice. Solid-lines polygons: home ranges with N of fixes ≥ 20 ; dashed-line polygons: home ranges with N < 20 fixes. Note that all ranges are located on one side of the ski-piste.

Below:

the
by
points)
(black
day
the
(N=19),
often
than
(even
time).



locations of all
375 fixes of fat
dormice
collected: 220
night (grey
and 155 by day
points).
Locations by
coincide with
resting sites
which were
used by more
one animal
at the same

Table 1 Translocation experiment. Number of individuals trapped, translocated across the ski-piste and returned to their capture area by crossing back to the ski-piste. The return index (i.e. the number of individuals that successfully crossed the ski-piste as a percentage of the total number of translocated individuals) is also provided.

| Year | Species | N trapped | N translocated | N returned | Return index (%) |
|------|-----------------------------|-----------|----------------|------------|------------------|
| 2008 | <i>Apodemus flavicollis</i> | 35 | 27 | 3 | 11.11 |
| | <i>Glis glis</i> | 14 | 11 | 4 | 36.36 |
| 2010 | <i>Apodemus flavicollis</i> | 109 | 109 | 20 | 18.35 |
| | <i>Myodes glareolus</i> | 30 | 30 | 6 | 20.00 |

Table 2

Selectio

n of

resting

sites by the fat dormouse. Mean values (\pm standard deviations) of habitat variables in resting sites and random points. *P*-values are derived from *t*-tests.

| Variables | Resting sites (n = 19) | Random points (n = 38) | <i>P</i> |
|----------------------|---------------------------|---------------------------|----------|
| herb cover (%) | 6.00 \pm 7.90 | 2.00 \pm 12.7 | 0.003 |
| litter cover (%) | 38.40 \pm 19.30 | 75.80 \pm 17.04 | <0.001 |
| soil cover (%) | 1.00 \pm 2.30 | 1.00 \pm 2.00 | N.S. |
| rock cover (%) | 36.74 \pm 22.76 | 6.38 \pm 9.12 | <0.001 |
| shrub cover (%) | 7.00 \pm 12.00 | 0.00 \pm 1.10 | 0.001 |
| dead wood cover (%) | 10.53 \pm 4.97 | 14.13 \pm 6.09 | N.S. |
| canopy closure (%) | 80.00 \pm 18.26 | 83.00 \pm 15.92 | N.S. |
| number of stumps (N) | 0.11 \pm 0.31 | 0.58 \pm 0.90 | 0.03 |

Table 3

Results of PCA carried out on eight habitat structure variables. The highest factor loadings are in bold type.

| Variables | Factor loadings | | |
|--------------------------------|-----------------|---------------|---------------|
| | PC1 | PC2 | PC3 |
| herb cover (%) | 0.870 | 0.136 | -0.142 |
| litter cover (%) | -0.875 | 0.343 | -0.234 |
| soil cover (%) | 0.458 | -0.154 | -0.576 |
| rock cover (%) | 0.602 | -0.570 | 0.505 |
| shrub cover (%) | 0.474 | 0.484 | -0.092 |
| dead wood cover (%) | -0.580 | -0.432 | 0.003 |
| canopy closure (%) | -0.683 | 0.104 | 0.393 |
| number of stumps (N) | -0.344 | -0.543 | -0.559 |
| Percentage variation explained | 40.50 | 15.13 | 14.22 |

Table 4

Information
-theroretic
statistics for
the first
four models
in rank

order. The models are ranked using AIC_c.

| Model | -2*log-likelihood | K _i | AIC _c | Δ _i | ω _i |
|-------------|-------------------|----------------|------------------|----------------|----------------|
| PC1 PC3 | 37.45 | 3 | 43.93 | 0 | 0.75 |
| PC1 PC3 PC2 | 37.36 | 4 | 46.18 | 2.25 | 0.25 |
| PC1 | 53.18 | 2 | 57.42 | 13.49 | 0.00 |
| PC1 PC2 | 52.71 | 3 | 59.19 | 15.26 | 0.00 |