

Forest bird diversity and ski-runs: a case of negative edge effect

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Abstract

Among tourist activities in the Alps, winter sports have a prominent role because of the large scale of changes they cause at the habitat and landscape level. We have analysed whether ski resorts lead to significant threats to the avian diversity in the coniferous forests of the western Italian Alps, by comparing the bird communities of plots located in (1) the forest interior, (2) forest at the edge of ski-runs and (3) forest at the edge of pastures (the latter two are anthropogenic elements of forest fragmentation). Ski-runs produce a negative edge effect in the study forests: plots at their edges present lower bird species richness and Shannon diversity than those located in the forest interior or at the edges of pastures. In particular, birds typical of ecotone habitats seem to favour forest plots set at the edge of pastures. Ski-run-edges are linear landscape features that create high contrast edges; conversely, vegetation structure is more complex at the edge of pastures, attracting a rich and diverse avifauna. In the study area, pastures tend to be abandoned whereas winter sport resorts are increasing in extent. Accordingly, there is a need for coordinated management and cooperation between sport- and land-management agencies, in order to preserve native biodiversity while simultaneously managing land for sport activities.

INTRODUCTION

The creation of edges, i.e. transition zones between adjacent habitats, is one of the effects of habitat fragmentation (Murcia, 1995). Historically, land managers considered habitat fragmentation to be beneficial for biodiversity (Leopold, 1933), on the basis of what was later called the 'edge effect', i.e. the hypothesis that species richness and density increase at the border between different habitats (Odum, 1971). Recent investigations, however, have described radical changes in community structure at edges, suggesting problems from a diversity perspective (Matlack & Litvaitis, 1999). These problems increase when anthropogenic intervention determines a proliferation of edges, emphasising the natural physical gradients in topography, hydrology and substrate (Saunders, Hobbs & Margules, 1991; Andrén, 1994; Rochelle, Lehmann & Wisniewski, 1999; Shochat, Abramsky & Pinshow, 2001). 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

(Andrén & Angelstam, 1988; Andrén, 1992; Faaborg *et al.*, 1995; Kurosawa & Askins, 2003), inhibition of dispersal and reduction of home range (Forman, 1997) and intensification of human disturbance (McGarigal *et al.*, 2001). In Europe, the effects of habitat fragmentation have been severe in lowland forests that have experienced a long history of anthropogenic disturbances (Hanson, 1983; Cushman & McGargal, 2003; Gurdebeke *et al.*, 2003). The impact of human activities in high-elevation environments is more recent and a common form of disturbance comes from the development of winter sport resorts. Ski-runs, in particular, brought about considerable damage both above and below the timberline: forest tracts are abruptly clear-cut, bulldozers and power shovels are used for soil removal (to provide comfortable slopes for skiers) and artificial seeding, if any, is conducted to control for soil erosion (Siniscalco *et al.*, 1997; Urbanska, Erdt & Fattorini, 1998; Tsuyuzaki, 2002). After construction, tree pruning and cutting of shrubs are carried out at regular intervals and large amounts of chemicals are spread for soil stability (Barni, Siniscalco & Montacchini, 2002).

Despite ski-runs becoming a common feature in alpine landscapes, there is a paucity of research on their effects on wildlife (Delmas, 1986; Watson & Moss, 2004). This study was undertaken to provide information on the effects of ski-runs on the bird communities of the coniferous forests of the Alps. We compared bird diversity and community composition in plots located in (1) the

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forest interior, (2) forest at the edge of ski-runs and (3) forest at the edge of pastures. In particular, we examined whether avian diversity is greater in forest plots located at the edge of an open space – ski-run or pasture – than in the forest interior (as expected when an edge effect occurs). Like ski-runs, pastures have an anthropogenic nature, but while the former form abrupt edges, pastures tend to create more ragged edges. We also investigated bird–habitat relationships, to determine important floristic and structural components of the habitat of the alpine coniferous forest avifauna.

METHODS

Study area

The study was carried out in the coniferous forests of the Alta Val Susa, Val Chisone and Val Germanasca, in the western Italian Alps. We surveyed 10 localities comprising ski areas and a Natural Park (Fig. 1). In 2006, the XX Olympic Winter Games will take place in the study area. Since the 1970s, ski-runs have been constructed both on high-elevation grasslands and within coniferous forests; they were established by scraping off the extant vegetation

and the topsoil and by artificially seeding with prevailing native herbs. Coniferous forests of the area are dominated by the larch *Larix decidua*, but the fir *Abies alba*, Norway spruce *Picea abies*, Arolla pine *Pinus cembra* and Scots pine *Pinus sylvestris* also occur. Broadleaved trees (*Fraxinus excelsior*, *Acer pseudoplatanus*, *Betula pendula*, *Alnus viridis*, *Corylus avellana*, *Sorbus spp.*, *Salix spp.*) are found as scattered individuals within the coniferous matrix. The understorey is sparse, mainly composed of *Juniperus*, *Rhododendron*, *Vaccinium* and *Arctostaphylos spp.*

Bird and habitat sampling design

Field work was carried out in April, May and June 2003. Birds were counted using 50-m fixed radius point-counts, between sunrise and 5 h later in good weather conditions (Bibby *et al.*, 2000). All birds detected during a 7 min period, aurally and/or visually, were recorded. Overall, 252 point-counts were made at 1100–2200 m above sea-level (a.s.l.). The exact location of plots was established in the field by means of a Global Positioning System (GPS) Garmin eTrex® Navigator. Each plot was located at a minimum distance of 200 m from the next nearest sampling plots and we were careful not to record the same

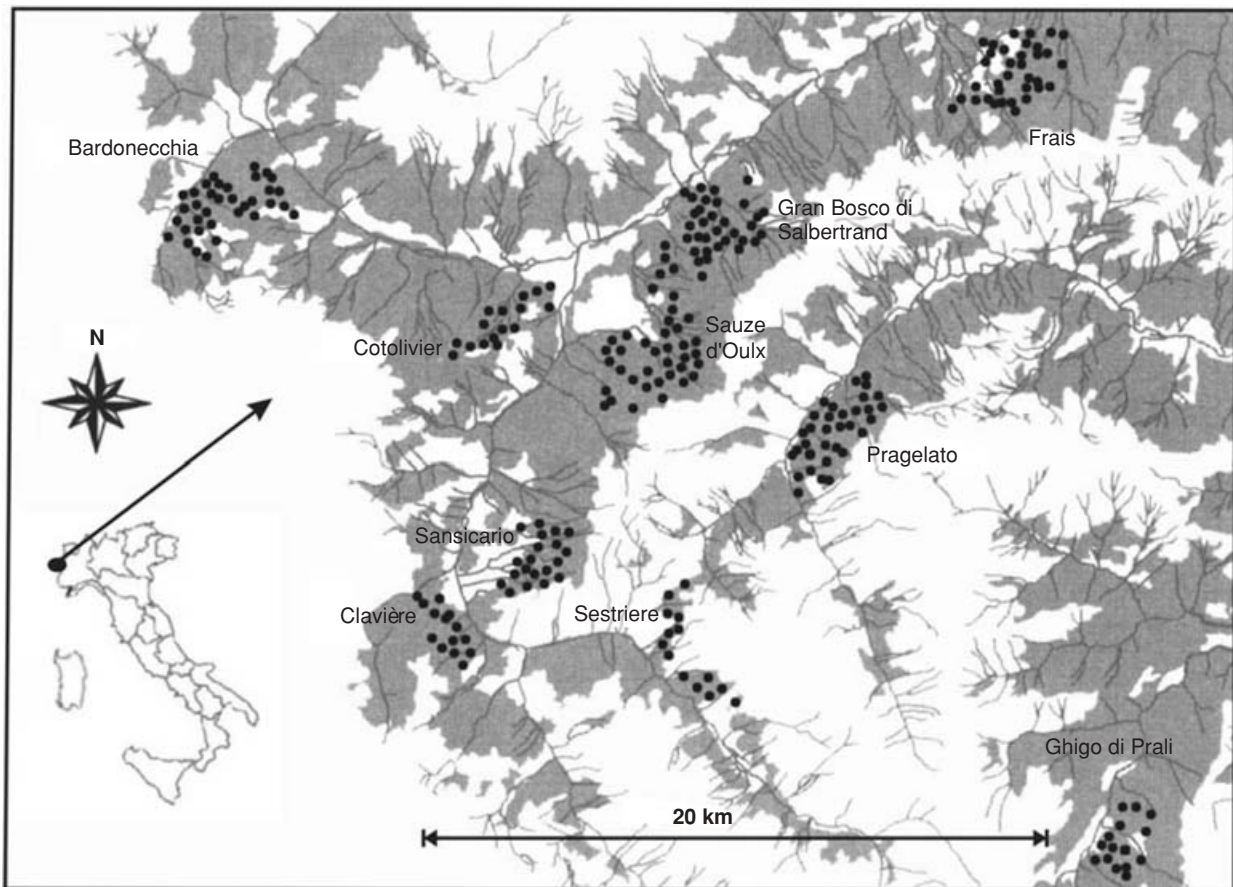


Fig. 1. Geographical location and map of the study area. Survey plots (circles), forests (grey areas) and water courses (lines) are shown. Ski-run strips and small pastures (< 5 ha) cannot be distinguished at this detail. The study ski resorts are located in Sestriere, Clavière, Sansicario, Bardonecchia, Fraix, Ghigo di Prali, Pragelato and Sauze d'Oulx. The Gran Bosco di Salbertrand is a Natural Reserve.

individuals on neighbouring points. Three types of plots were defined: forest-interior plots ($n = 112$), ski-run edge plots ($n = 68$) and pasture edge plots ($n = 72$). Ski-run strips were 30–50 m wide and > 500 m long, pastures covered > 1.5 ha. The centre of edge plots was located 50 m from ski-runs and pastures, so that the external perimeter of the plots embraced forest edge on one side. The centre of forest interior plots was located > 200 m from edges (the external perimeter on one side was at a minimum distance of 150 m from edges).

In circular plots of 20 m radius (centred in each census plot), structural parameters of the vegetation were measured. Tree height was measured using a clinometer, tree diameter at breast height was determined using a tape and tree density was established as the inverse of the distance between the nearest trees paced in metres. Ten measurements per plot were taken for tree height, diameter and distance and the averages of these habitat measurements were used in statistical analyses. The variability in canopy profile for each plot was determined through the coefficient of variation of tree height ($CV = SD/\text{mean height} \times 100$). In each point count station of 50 m radius, all trees > 6 cm diameter at breast height were counted and their taxonomic identity recorded, to derive a measure of arboreal diversity per plot (Shannon index: $H' = -\sum p_i \times \ln p_i$, where p_i is the relative frequency of tree species i).

Hence, local habitat at each count-station was depicted by means of six parameters: arboreal diversity (AH), relative abundance of larch (the dominant tree, %L), tree height (H), diameter (DBH), density (D) and variability in canopy profile (CVH). Avian community was described in terms of bird species richness (S), diversity (Shannon index, BH) and the density of three ecological groups of birds: woodland species (birds typical of forest and open forest habitats), ecotone-shrub species (species that use grassland and woodland alternatively or dwell in shrubby areas) and grassland species (birds that require open fields both for breeding and foraging).

Data analysis

Differences between plot types

We tested for differences in mean bird species richness, diversity and density of woodland, ecotone-shrub and grassland species between the three plot types (forest-interior, ski-run-edge and pasture-edge) by means of nested ANOVAs (plots nested into 10 study localities). The values of Shannon diversity was transformed to logarithms ($y = \log(x) + 1$) and those of species richness and density of the three ecological groups were transformed to square roots ($y = \sqrt{x + 0.5}$) to attain a normal distribution.

Relationships between bird community and habitat

Principal component analysis (PCA: Gaunch, 1984) was chosen to compensate for multicollinearity and to reveal patterns in the data for vegetation structure (DBH, H, D

and CVH variables), using standardised data (zero mean and unit standard deviation).

We used generalised linear models to test for the effects of vegetation structure (three scores of PCA), floristics (arboreal diversity, percent larch cover), elevation, locality and plot type (categorical variable defining forest interior, ski-run- and pasture-edges) on bird species richness, diversity and the abundance of the three ecological groups of birds. Species richness and bird abundance values matched Poisson distribution, whereas species diversity matched a Gaussian distribution. Both Poisson/Gaussian regressions and Akaike's Information Criterion (AIC: Akaike, 1973) were 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 with 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 & Anderson, 1998).

Generalised linear models and AIC were calculated using the R Package (Ihaka & Gentleman, 1996).

Relationships between bird species and habitat

Density of bird species at each plot was compared with vegetation characteristics by means of the Canonical Correspondence Analysis (CCA). This is a multivariate technique that ordines plots using both a primary matrix of species densities and a secondary matrix of environmental variation (ter Braak, 1986). The primary matrix included 29 bird species, i.e. those contributing with at least eight individuals to the data set, the secondary matrix included floristic and physiognomic descriptors (AH, %L, H, DBH, D and CVH), elevation and plot type. To assess the significance in the CCA axes, we used Monte Carlo simulations to test the hypothesis that there was no correlation between the primary (bird) and secondary (environment) matrices: P values were based on the proportion of 1000 Monte Carlo simulations with an eigenvalue greater than the observed eigenvalue. CCA was performed using PC-ORD (McCune & Mefford, 1999).

RESULTS

Differences between plot types

Overall, 1256 individuals from 42 species were sampled in 252 plots (see Appendix 1 for a complete list of bird species and Appendix 2 for the distribution of points within plot types and localities). Forest-interior, ski-run and pasture-edge stations showed significant differences in terms of bird diversity and species richness and no significant interaction resulted between locality and plot type (Table 1). Plots located at the edge of pastures support

Table 1. Mean \pm SD of bird species richness, diversity and abundance of woodland, ecotone-bush and grassland species per plot type

	(1) Forest interior	(2) Pasture-edge	(3) Ski-run-edge	Inter-plot differences (nested ANOVA)	Significant pair-wise comparisons at $P < 0.05$
Species richness	4.0 \pm 1.7	4.5 \pm 1.7	3.4 \pm 1.7	F _{2,225} = 7.6***	(1) vs (3), (1) vs (2), (2) vs (3)
Diversity	1.2 \pm 0.5	1.4 \pm 0.4	1.0 \pm 0.7	F _{2,225} = 7.7***	(1) vs (3), (2) vs (3)
Abundance of woodland species	4.5 \pm 2.0	4.7 \pm 2.2	3.6 \pm 2.1	F _{2,225} = 5.1**	(1) vs (3), (2) vs (3)
Abundance of ecotone-bush species	0.5 \pm 0.8	1.0 \pm 1.2	0.7 \pm 1.0	F _{2,225} = 5.3**	(1) vs (2)
Abundance of grassland species	0.02 \pm 0.2	0.1 \pm 0.4	0.2 \pm 1.2	F _{2,225} = 2.2	

Inter-plot differences were tested with nested ANOVAs (plot type nested into locality). Least-squares deviation (LSD) post-hoc tests were used for pair-wise comparisons of means. vs, versus.

** $P < 0.01$, *** $P < 0.001$.

the greatest bird species richness and diversity, whereas those set at the edge of ski-runs presented the lowest values. Woodland species density was greatest in forest interior and pasture-edge plots, numbers of ecotone-shrub birds peaked in plots at the edge of pastures (Table 1). Using one-way ANOVAs, we tested for differences between bird diversity of plots located in the surroundings of ski-runs and diversity of plots located further away (distance classes: < 0.5 km, $0.5-1$ km and > 1 km). When plots located at the edge of ski-runs were included in the analyses, bird species richness and diversity were significantly lower in forests around ski resorts than in forested areas located at least 1 km apart from them (S: $F_{2,249} = 4.2$, $P < 0.05$; BH: $F_{2,249} = 3.4$, $P < 0.05$). However, when only forest interior and pasture-edge plots were considered, no significant difference was found between distance classes (all $P > 0.05$), suggesting that forest bird diversity only drops in the close proximity of a ski-run.

Relationships between bird community and habitat

The first three principal components (PC1, PC2, PC3) accounted for 89% of the total variation in the vegetation structure matrix, with eigenvalues > 1 . Tree height and diameter at breast height showed the highest correlation with PC1 scores (suggesting a gradient from young *versus* old stands), the variability in tree height provided the

Table 2. Results of principal component analysis carried out on habitat structure data

	Factor loadings		
	PC1	PC2	PC3
Tree diameter (cm)	0.62	0.46	0.34
Tree height (m)	0.95	0.06	0.08
Coefficient of variation of tree height (%)	-0.13	-0.97	-0.04
Tree density (1/distance between trees)	-0.14	-0.06	-0.98
Eigenvalues	1.32	1.15	1.07
% Total variance	0.33	0.29	0.27

The highest loadings are in bold type.

major loading (negative) on PC2, tree density showed a negative correlation with PC3 (Table 2).

Results of generalised linear models of bird species richness, diversity, density of woodland, ecotone-bush and grassland birds on environmental predictors are shown in Table 3. Bird species richness and diversity were best modelled by plot type alone, with the AIC minimised for just this variable (S: AIC = 991, BH: AIC = 345); all other variables and their combinations had greater AIC values (S: AIC > 1000 , BH AIC > 360). Poisson/Gaussian regressions confirmed these results, since they were significant only when plot type was entered, although

Table 3. Generalised linear models of bird species richness, diversity, density of woodland, ecotone-bush and grassland birds on environmental predictors (arboreal diversity, larch cover, elevation, plot type, locality, PCA scores for structural variables)

Predictor	β	SE	P
Species richness			
Plot type pasture-edge	0.29	0.09	< 0.001
Plot type forest interior	0.16	0.08	< 0.05
AIC = 991			
Diversity			
Plot type pasture-edge	0.32	0.08	< 0.001
Plot type forest interior	0.18	0.07	< 0.01
AIC = 345			
Abundance of woodland birds			
Plot type pasture-edge	0.21	0.08	< 0.05
Plot type forest interior	0.12	0.08	= 0.1
Elevation	-0.53	0.23	< 0.05
Larch cover	-0.07	0.03	< 0.05
AIC = 1076			
Abundance of ecotone-scrub birds			
Plot type pasture-edge	0.56	0.19	< 0.01
Elevation	-0.13	0.67	< 0.001
AIC = 573			
Abundance of grassland birds			
PC1	-0.39	0.20	< 0.05
PC3	-0.56	0.19	< 0.01
Plot type forest interior	-2.61	0.76	< 0.001
AIC = 173			

PC1 is an indicator of stand age, PC3 of tree density. Only variables included in the best model (i.e. that minimising AIC) are shown; variables were added sequentially. SE, standard error.

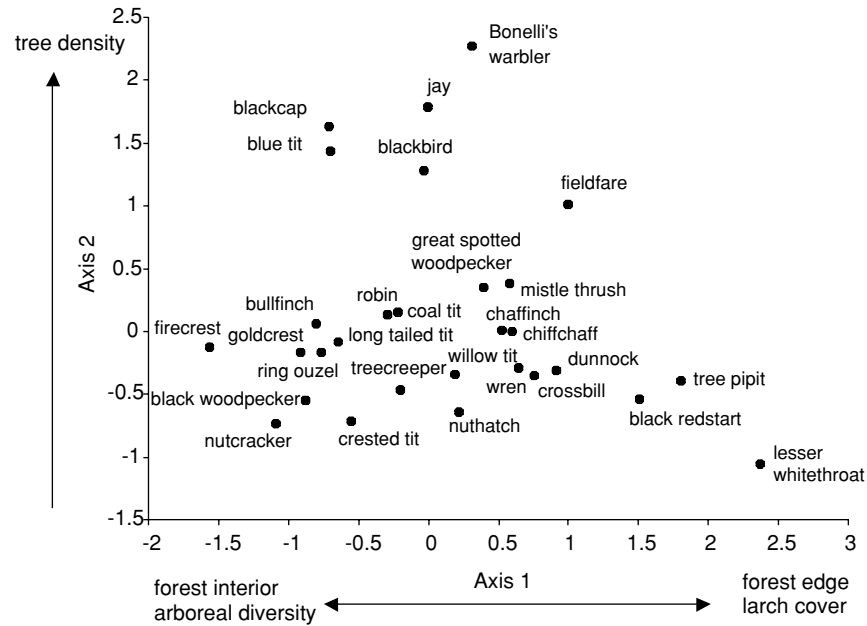


Fig. 2. Scatterplot of the bird community along the first two axes of Canonical Correspondence Ordination (CCA).

the model only explained 5% of the total variation. The density of woodland species decreased with elevation and larch cover and increased in forest interior and pasture-edge plots; birds of the ecotone and shrubs were associated with pasture-edge and high elevation plots, while grassland species only inhabited young woodlots with sparse tree cover at the margin of forest (Table 3).

Relationships between bird species and habitat

In canonical correspondence analysis (CCA), the first CCA axis represented a gradient from high tree diversity plots located in forest interior to larch-rich sites of forest margin (AH: $r = -0.514$; forest-interior: $r = -0.401$; pasture-edge: $r = 0.24$; ski-run-edge: $r = 0.22$; %L: $r = 0.39$), the second axis represented increasing tree density (D: $r = 0.343$). Black woodpecker, treecreeper, nutcracker, firecrest, goldcrest and tits were associated with high arboreal diversity and forest interior plots, whereas lesser whitethroat, tree pipit, black redstart, dunnock and mistle thrush occurred at forest edges dominated by larches (Fig. 2). The first two ordination axes of CCA had significant canonical eigenvalues (< 0.005), as determined by the Monte Carlo test.

DISCUSSION

Among tourist activities in mountains, winter sports have a prominent role because of the large scale of changes they cause at the landscape level and the large demand on energy supply. In particular, the construction of ski-runs in the study area requires the destruction of the pre-existing ecosystems through the removal of topsoil and extant native vegetation (both herbaceous and arboreal) in strips typically 30–50 m wide (Siniscalco & Montacchini, 1990).

Several studies have shown that plant diversity in ski-runs is lower than that of nearby grasslands (Urbanska *et al.*, 1998); vegetation successional stages are also disrupted (Tsuyuzaki, 2002). The effects on the faunal components are less studied and more varied: Shine, Barrott & Elphick (2002), for instance, found that artificial corridors in mountainous forests enable reptiles to penetrate higher into the forest, as these species take advantage of higher solar radiation in anthropogenic clearcuts. On the other hand, Watson & Moss (2004) found out that the breeding success of ptarmigan *Lagopus mutus* can drop as a consequence of ski-development in Scotland. The results of this study show that bird species richness and diversity of forests perforated by ski-runs are significantly lower than those of undisturbed forests. This could be ascribed to the negative edge effect that ski-runs produce in the forest: plots at their edges present lower bird diversity and species richness than those far from edges; conversely, species richness is enhanced when the forest grades into a pasture, suggesting that the latter element causes a local positive edge effect in the forest. We hypothesise that the factors that are responsible for the observed differences are related to the different structure and resource availability of these two types of forest edges. First, ski-runs are linear landscape features that create high contrast edges and bisect patches: the forest ends abruptly and shrub and tree encroachment is prevented by regular pruning and cutting. Second, several ski-runs, especially the steepest ones, have a high proportion of bare ground, due to soil erosion, compaction and the use of chemicals in artificial snow; these factors might limit, in turn, the resources available to forest birds in nearby open habitats. Conversely, at the edge of pastures the shrub layer is denser (due to extra light) and it is not removed as in ski-runs. Furthermore, the shrubs at forest edges may flower more regularly than in the heavily shaded forest interior and the light,

warm conditions at the edge may increase insect density and, in turn, insectivorous bird density. Several studies in temperate forests have shown that the presence of bushes and grassy headlands in forest margins can increase bird diversity (Kroodsma, 1984; Fuller & Warren, 1991; Fautsch, Delvingt & Paquet, 2003). In addition, pasture-edges may offer more suitable habitats for birds because they are older than ski-run edges: both the structure and the plant composition are generally thought to be more complex along old, established edges where there has been a constancy of light penetration (Fuller, 1995). Eventually, grazed patches and their surrounding forest edges may be richer in particular invertebrates that are important prey items for birds, such as bionids and leatherjackets (flies), which depend upon the availability of organic matter (dung) (McCracken, Foster & Kelly, 1995; Vickery *et al.*, 2001).

Typical ecotone bird species preferentially dwell in plots at the edges of pastures and at high elevations, whereas woodland birds are more abundant in forest interior or at the edge of pastures and tend to avoid pure larch sites and high altitude. The fact that forest interior and pasture edge support similar overall abundance of woodland species probably depends on the relative paucity of true forest specialists, which make up a minor share of woodland birds in the study area. Grassland birds are found only close to the edges and prefer young forests where trees are very sparse. All in all, forest plots at ski-run edges are avoided by both typical forest birds and by ecotone birds, which constitute the bulk of the species sampled. Although this study concentrated on forest habitats, it is worth noting that several open-habitat species were more abundant, or occurred only, in pastures and avoided ski-runs: woodlark *Lullula arborea*, rock bunting *Emberiza cia*, yellowhammer *Emberiza citrinella*, red-backed shrike *Lanius collurio*, whinchat *Saxicola rubetra* and rock sparrow *Petronia petronia* (pers. obs.).

Although bird diversity peaks in forest plots at the edges of pastures, CCA shows that forest interior habitats are important for several species, such as the treecreeper, bullfinch, *Regulus* spp., black woodpecker, nutcracker and most tits; these species are also associated with plots with great tree diversity. Conversely, the lesser whitethroat, tree pipit, black redstart, crossbill and dunnock seem to prefer larch-rich habitats at forest edges. Stand age, as indicated by tree height and diameter, is a poor predictor of individual species distribution and this contradicts a widely held general view that forest age is important to the distribution of birds in temperate woodlands (Lack, 1939; Lack & Lack, 1951; Moss, 1978; Helle & Mönkkönen, 1990).

A possible caveat of this research concerns the assessment of habitat quality from measures of bird densities, rather than directly estimating bird breeding success. However, the aim of this study was to investigate the value of different forest plots for the bird community on the whole. Ski-runs do negatively affect bird diversity *per se* and this has to be viewed as detrimental, irrespective of the effects on breeding success.

Despite its short-term nature, this study shows that the occurrence of ski-runs in the forested landscapes of

the Italian Alps lowers bird diversity, since a negative edge effect seems to occur. Plots at the edge of pastures have the greatest diversity, but they are avoided by some forest specialists, such as treecreeper and some *Parus* species. The latter species are priority species for forest-conservation (*sensu* Tucker & Evans, 1997) and their dependence upon forest interior emphasises the role of continuous habitat in the conservation of forest specialists. At present, forest clearing for winter sport activities is the major force driving the fragmentation of the coniferous forests, since there is a generalised trend towards pastoral abandonment in several alpine valleys and most grazed fields in the montane belt turned (or are turning) into forests (Laiolo *et al.*, 2004). In view of this, the only way to preserve the biodiversity of the area seems to be that of restoring the gradual transition from forest to the open habitat created by ski-runs. This could be achieved without compromising the safety of the ski-runs, by managing edge vegetation and encouraging side canopies, because physical gradients are much less pronounced behind close edges (Matlack & Litvaitis, 1999). The value of these measures in promoting natural diversity should be tested experimentally, through coordinated management and improved cooperation between sport- and land-management agencies, which should have the mandate to maintain native biodiversity while simultaneously managing land for commodity production, recreation and other objectives. Eventually, studies on the ecological impacts of alpine sport resorts on wildlife should also be encouraged outside the winter period, to understand whether disturbed ecosystems have already moved outside of their natural range of variation and to identify threshold levels within which human activities can be sustainable.

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APPENDIX 1. List of the bird species recorded in the 252 plots. Species were classed as grassland, ecotone-shrub and woodland birds according to their ecological preferences

Common name	Scientific name	Ecological group
Black grouse	<i>Tetrao tetrix</i>	Ecotone-shrub
Great spotted woodpecker	<i>Dendrocopos major</i>	Woodland
Black woodpecker	<i>Dryocopus martius</i>	Woodland
Green woodpecker	<i>Picus viridis</i>	Woodland
Tree pipit	<i>Anthus trivialis</i>	Ecotone-shrub
White wagtail	<i>Motacilla alba</i>	Grassland
Wren	<i>Troglodytes troglodytes</i>	Woodland
Duncock	<i>Prunella modularis</i>	Ecotone-shrub
Whinchat	<i>Saxicola rubetra</i>	Grassland
Robin	<i>Erithacus rubecula</i>	Woodland
Black redstart	<i>Phoenicurus ochruros</i>	Grassland
Redstart	<i>Phoenicurus phoenicurus</i>	Woodland
Ring ouzel	<i>Turdus torquatus</i>	Ecotone-shrub
Blackbird	<i>Turdus merula</i>	Woodland
Fieldfare	<i>Turdus pilaris</i>	Ecotone-shrub
Mistle thrush	<i>Turdus viscivorus</i>	Ecotone-shrub
Lesser whitethroat	<i>Sylvia curruca</i>	Ecotone-shrub
Garden Warbler	<i>Sylvia borin</i>	Ecotone-shrub
Blackcap	<i>Sylvia atricapilla</i>	Woodland
Bonelli's warbler	<i>Phylloscopus bonelli</i>	Woodland
Chiffchaff	<i>Phylloscopus collybita</i>	Woodland
Goldcrest	<i>Regulus regulus</i>	Woodland
Firecrest	<i>Regulus ignicapillus</i>	Woodland
Long-tailed tit	<i>Aegithalos caudatus</i>	Woodland
Coal tit	<i>Parus ater</i>	Woodland
Willow tit	<i>Parus montanus</i>	Woodland
Crested tit	<i>Parus cristatus</i>	Woodland
Blue tit	<i>Parus caeruleus</i>	Woodland
Great tit	<i>Parus major</i>	Woodland
Treecreeper	<i>Certhia familiaris</i>	Woodland
Short-toed treecreeper	<i>Certhia brachydactyla</i>	Woodland
Nuthatch	<i>Sitta europaea</i>	Woodland
Jay	<i>Garrulus glandarius</i>	Woodland
Nutcracker	<i>Nucifraga caryocatactes</i>	Woodland
Carrion crow	<i>Corvus corone corone</i>	Ecotone-shrub
Chaffinch	<i>Fringilla coelebs</i>	Woodland
Citrel finch	<i>Serinus citrinella</i>	Woodland
Redpoll	<i>Carduelis flammea</i>	Woodland
Bullfinch	<i>Pyrrhula pyrrhula</i>	Woodland
Crossbill	<i>Loxia curvirostra</i>	Woodland
Rock bunting	<i>Emberiza cia</i>	Grassland
Yellowhammer	<i>Emberiza citrinella</i>	Grassland

APPENDIX 2. Number of points sampled in each plot type and locality

Locality	Forest interior	Pasture-edge	Ski-run-edge
Bardonecchia	14	5	16
Cotolivier	10	6	–
Sauze d'Oulx	11	6	17
Gran Bosco di Salbertrand	26	7	–
Frais	9	16	8
Sansicario	3	7	10
Clavière	12	–	3
Sestriere	1	7	6
Pragelato	19	14	3
Ghigo di Prali	7	5	5
Total	112	72	68