Effect of agro-forestry and landscape changes on common buzzards (*Buteo buteo*) in the Alps: implications for conservation

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Abstract

In Italy, pre-Alpine forests, once managed through coppice silviculture, are being converted to mature woodland, while land abandonment is causing woodland expansion and erosion of open habitats. Based on habitat-selection analyses, we predicted the impact of such changes on common buzzards (*Buteo buteo*), which depend on forested and open areas for nesting and foraging. Compared to availability, at a micro-scale buzzards selected nests higher above ground and on trees frequently covered by ivy. At the landscape-scale, buzzards avoided roads and conspecifics, while selecting rugged areas with high habitat heterogeneity, probably related to a varied food supply. Productivity was related to the availability of arid habitats, probably because of their richness in main prey species. Finally, population density was negatively related to the abundance of eagle owls (*Bubo bubo*), a potential predator of adults and nestlings, and positively related to the availability of woodland, a low predation-risk habitat rich in food and nest-sites. Therefore, buzzard settlement, density and productivity depended on the complex interplay of food availability, human persecution and predation risk. Thus, the current landscape changes would benefit buzzards by providing more nest-sites, but would be detrimental because of the lower productivity associated with the disappearance of dry open areas. Proposed conservation guidelines focus on conversion of coppice woodland to mature forests and active management of dry heath, a conservation sensitive habitat, through controlled burning.

INTRODUCTION

The traditional landscape of the European Alps is going through a relatively fast process of land-use changes. In the lower-elevation mountains of the pre-Alps, the landscape was traditionally dominated by large forests interspersed with open habitats, mainly meadows. The forests were managed using a coppice silvicultural system (Matthews, 1989), while open habitats were artificially maintained for livestock grazing and hay production, an agro-forestry and pastoral system that dates back to 6000 years ago (Lichtenbergen, 1994). The management practices of both these landscape features have rapidly changed in the past decades because of land abandonment associated with the declining profitability of livestock rearing and coppice silviculture (Buckley, 1992; CIPRA, 2001). As a result, open habitats are being rapidly lost through shrub encroachment and woodland expansion (e.g. Pedrini & Sergio, 2001, 2002), while large areas of forest have been left unmanaged for 3–4 times the original rotation of 10–20 years (Sergio, Pedrini & Marchesi, 2003*d*). Some of these forests are naturally evolving into mature forest, while incentives from local administrations and the Common Agricultural Policy (C.A.P.) of the European Union favour their conversion to mature woodland (e.g. I.P.L.A., 2000). Therefore, large areas of forest are planned or likely to be converted to mature timber. Such radical changes impose an urgent need for investigation of their potential impact on the local fauna and for conservation proposals based on quantitative studies. This would increase the probability of integrating them into forestry plans and incentive schemes (e.g. C.A.P. subsidies, or timber certification: Pain & Pienkowski, 1997; Bennet, 2000).

Here, we provide such a study by focusing on the common buzzard (*Buteo buteo*), a medium-sized diurnal raptor widely distributed throughout the Palearctic. In the Italian Alps, its populations are stable, although few quantitative data are available (Sergio *et al*., 2002) and nothing is known of its habitat requirements. Nests are uniformly dispersed and located on cliffs or trees (Sergio *et al*., 2002). The diet is dominated by snakes, mainly

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occurring in open, arid habitats and by various woodland species of small mammals and birds (Scandolara & Sergio, 2001).

Here, we (1) analyse the factors affecting nest-site selection by buzzards, (2) examine the reproductive consequences of such habitat choices, (3) investigate the population effects of spatial variations in habitat quality, (4) predict the potential impact of the ongoing land-use changes and (5) propose conservation-management guidelines. We assume that, if the above-cited landscape changes negatively affect the populations of such a generalist species, they could affect even more the populations of other more exigent and specialised species.

STUDY AREAS

The study area was a 130-km^2 plot located in the central Italian pre-Alps (45°55′N, 8°50′E), near the shore of Lake Lugano (hereafter ‘Lugano area’). Elevation ranged from 275–1125 m above sea level (a.s.l.). The landscape was characterised by mountain slopes covered by deciduous woodland, interspersed with small to medium-sized cliffs and scarce open areas, caused by regular burning or sheep grazing and mainly covered by grassland and sparse bushes. The valley floors were intensively cultivated or urbanised.

Woodland was mainly dominated by deciduous species, originally managed as coppice but now left unmanaged (neglected coppice: Buckley, 1992). As a result, most of the woodland consisted of a homogeneous cover of young second-growth forest. Mature trees, originally retained as seed bearers, were scarce and present as widely scattered individuals or in small clumps (coppice with standards system: Matthews, 1989). In particular, 21% of the woodland area was dominated by sweet chestnut (*Castanea sativa*), 20% by European beech (*Fagus sylvatica*), 19% by a mixture of sweet chestnut and oak species, 18% by European hop-hornbeam (*Ostrya carpinifolia*), 5% by oak species, 5% by locust (*Robinia pseudoacacia*), 2% by conifers and 10% by other tree species (Geographic Information System (GIS) analysis from Tosi *et al*., 2000).

To further test the effect of environmental variables on buzzards at the population-level, between 1996 and 2000 we censused buzzards in eight other study areas scattered throughout the Italian Alps (Fig. 1). The landscape and elevation of all of these areas was comparable to that of the Lugano plot (for details, see Sergio, Marchesi & Pedrini, 2003*a*; Sergio, Pedrini & Marchesis, 2003*b*). A further 100-km^2 study plot, located along the Noce Valley, was surveyed in 2001–2002.

METHODS

Field surveys and nest checks

In the Lugano area, buzzards were monitored between 1993 and 2003. We censused territorial pairs by looking at territorial displays and transfers of nest material during the pre-incubation period. Nests were visited when the nestlings were older than 45 days to record the number of fledged young (Sergio *et al*., 2002). Because of manpower limitations we collected only data on density in the other areas. Furthermore, we censused nests of eagle owls (*Bubo bubo*) in all the areas, because this species frequently prey on other raptors and may limit their populations (Marchesi, Sergio & Pedrini, 2002; Sergio *et al*., 2003*a*). Eagle owls were absent from the Lugano area.

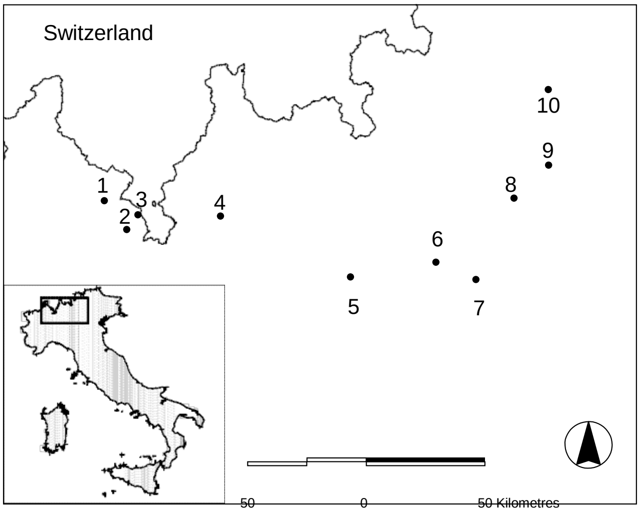

Fig. 1. Location of common buzzard study areas in the Italian Alps (1993–2003): 1, lake Maggiore study area; 2, Lugano; 3, Ganna Valley; 4, Lecco; 5, Lake Iseo; 6, Idro; 7, Lake Garda; 8, Sarca Valley; 9, Adige Valley; 10, Noce Valley.

Selection of nesting habitat

The Lugano area supported a stable population of 40 buzzard territories. To avoid pseudo-replication, in each analysis we used only one randomly selected nest among the alternative ones of each territory. Since nesting habitat selection may occur at multiple spatial scales (e.g. Sergio & Bogliani, 2000; Penteriani, Faivre & Frochot, 2001*a*), we carried out analyses (1) at a micro-scale, at the level of the nest-site and its immediate surroundings and (2) at a landscape or macro-scale, within a circle of 700-m radius centred on the nest. The measure of 700 m was chosen because this is approximately half the mean nearest neighbour distance (NND) in our population (Sergio *et al*., 2002). Since buzzards nest both in trees and on cliffs in our area, analyses at the micro-level were carried out separately for the two nest types.

To analyse factors affecting selection of cliff nests, we compared the variables recorded at 25 independent cliff nests (i.e. each from a different territory) with those recorded at 25 random cliffs (Appendix 1). To analyse factors affecting the selection of tree nests, we compared the variables recorded at 25 independent tree nests with those recorded at 25 random trees (Appendix 1). All random locations (cited above and below) were generated by means of the extension ‘Animal Movement’ in the GIS software ArcView (Hooge & Eichenlaub, 1997).

For tree nests, random trees were selected by (1) reaching the random location, (2) walking 100 m from it towards the North to minimise inadvertent observer bias (Redpath *et al*., 1998) and (3) selecting the nearest tree judged capable to support a hypothetical buzzard nest at > 8 m high (i.e. 1 m + the minimum height above ground of buzzard nests recorded in this study). To assess whether buzzards selected specific woodland features in the immediate surroundings of the nest, we measured variables related to woodland composition and structure within a 0.04-ha circular plot centred on each tree (see Appendix 1).

To analyse factors affecting selection of nest-sites at the landscape level, we compared the variables collected within 700 m of 40 independent nests and of 40 random locations (Appendix 1). Percentage extent of land-use types in the circle were calculated by accessing 1:10 000 land-use maps (Tosi *et al*., 2000). Since 26 out of the 40 randomly chosen nests were positioned on cliffs and 14 on trees, we plotted 26 random locations on cliffs and 14 on trees. Furthermore, the minimum NND between random locations was set to be the same as the minimum NND between buzzard territories. Overall, measured variables (Appendix 1) were related to (1) the structural characteristics of the nest-site and its immediate surroundings, (2) the distance to conspecifics, potential hunting grounds or sources of human disturbance and (3) the structure and composition of the landscape (see Austin *et al*., 1996 for a similar study design).

Statistical and GIS analyses

We used four logistic regressions with a backward stepwise procedure to analyse factors affecting nest-site selection at various spatial scales. Data on nest-site features were used to discriminate between:

(1) the characteristics of 25 cliff nests and 25 random cliffs (selection at the cliff-level: Appendix 1)
(2) the woodland characteristics in the immediate neighbourhood of 25 tree nests and of 25 random trees (selection at the nest-stand level: Appendix 1)
(3) the features of each of the above 25 nesting trees and those of one tree which was (i) randomly chosen from among those measured within the 0.04-ha plot around each nest and (ii) judged capable of supporting a hypothetical buzzard nest at > 8 m high, which allowed us to assess whether buzzards selected specific features of the nesting tree from among those available in its immediate vicinity (selection at the nest-tree level)
(4) the landscape features of 40 nest-sites and 40 random sites (selection at the landscape-level: Appendix 1)

To reduce collinearity and the number of variables presented to the multivariate models, we employed the method of variable reduction proposed by Green (1979) and commonly employed in habitat selection studies (e.g. Austin *et al*., 1996; Sergio & Bogliani, 2000 and references therein). In this method, pairs of strongly intercorrelated, explanatory variables ($r > 0.6$) are considered to be estimates of one underlying factor. Only one out of the two is retained for analysis, usually the one most likely to be perceived as more important by the study organism. Of the remaining variables, only those for which significant univariate differences ($P < 0.1$) were detected between nests and random locations were included in multivariate analyses.

For the analysis at the landscape scale, the predictive value of the logistic model was validated by applying it to 20 random locations and 20 nests (each from a different territory) located in the Noce study area (i.e. the farthest from the Lugano plot).

Factors affecting breeding performance

We used multiple regression to test the effect of environmental features on the number of young fledged within 31 territories checked at least once for breeding performance. To ensure data independence, for each territory we used data on breeding performance from one randomly selected year in which the territory was checked. To reduce the number of variables presented to the model, we employed only those that entered the above logistic models and those that were significantly related to the dependent variable in univariate correlations.

Population-level effects

For each of the 10 study areas, we measured landscape structure and composition (e.g. extent of land-uses, Shannon index of habitat diversity, length of habitat edges/unit area) by accessing various GIS land-use maps (C.E.C., 1993; Regione Lombardia, Direzione Generale della Presidenza, Servizio Sistema Informativo, 1998; Servizio Foreste, 1999). We then correlated average buzzard density with such environmental variables.

In all analyses, logistic and multiple regression models were run through a standard and a generalised linear model procedure (GLM, software GLIM 4). We then retained the model with the highest predictive power. GLM modelling procedures follow Crawley (1993). For all analyses, means are given ± 1 standard error (SE), tests are two-tailed and statistical significance was set at $\alpha \leq 0.05$. When multiple tests were performed on the same data set, the sequential Bonferroni correction was used to adjust the significance level (Rice, 1989).

RESULTS

Selection of cliff-sites

After variable reduction (see Methods and Table 1), three variables were presented to the stepwise logistic regression: cliff height, height of cliff complex and width of cliff complex. Of these, only cliff height ($\log_e$ transformed) had access to the logistic model ($B = 1.48 \pm 0.68$, Wald $= 4.73$, $P = 0.03$), which correctly

Table 1. Environmental variables recorded at 25 common buzzard cliff nests and at 25 cliffs randomly chosen in the study area (Italian pre-Alps, 1993–2002)

Variable	Cliff nests ($n = 25$)	Random cliffs ($n = 25$)
Nest height[a]	28.1 ± 3.9	
Height of cliff complex[b,+]	69.2 ± 8.9	50.0 ± 7.1
Width of cliff complex[b,+]	233.6 ± 38.5	138.8 ± 27.3
Elevation	606.8 ± 27.9	572.4 ± 32.6
% slope[b,**]	17.2 ± 0.8	14.3 ± 0.6
Micro-ruggedness index[c,**]	25.5 ± 1.4	20.7 ± 0.9
Distance to open[c]	144.0 ± 39.6	173.6 ± 29.8
Distance to path[c]	202.9 ± 25.3	162.1 ± 21.1
Distance to road[c]	454.9 ± 54.0	412.5 ± 54.7

Only significant variables (in univariate comparisons between nesting trees) are shown for conciseness of presentation; full table available on request from F.S.

Univariate differences between the two samples were tested by means of t-tests.

$^{+}0.05 < P < 0.1$; $^{*}P < 0.05$; $^{**}P < 0.01$.

[a] Only measured for nesting cliffs.

[b] t-test carried out on the variable $\log_e$ transformed.

[c] t-test carried out on the variable square root transformed.

Table 2. Environmental variables measured at 25 common buzzard tree nests and at 25 trees randomly chosen in the study area (Italian pre-Alps, 1993–2002)

Variable	Nest trees ($n = 25$)	Random trees ($n = 25$)
Nest height	14.2 ± 0.9	12.9 ± 0.6
Covered by ivy[c,**]	36.0[a]	0.0[a]
Mean tree height[**]	14.5 ± 0.6	12.2 ± 0.4
% with ivy[b,***]	12.3 ± 2.6	0.7 ± 0.4
Tree species richness[+]	3.6 ± 0.3	4.3 ± 0.3
Micro-ruggedness index[a,***]	15.6 ± 1.4	11.9 ± 0.8
Elevation[*]	491.8 ± 32.6	599.0 ± 40.4
Distance to open[c]	57.3 ± 9.2	57.2 ± 9.1
Distance to path[d]	163.9 ± 30.0	107.0 ± 21.4
Distance to road[d]	258.0 ± 38.4	291.1 ± 65.2
Distance to village[d,+]	790.2 ± 98.1	600.0 ± 114.9

Variables related to woodland structure were collected within a 0.04 circular plot centred on the nest or random site. Only significant variables (in univariate comparisons between nesting trees and random trees and between nesting trees and nesting cliffs) are shown for conciseness of presentation; full table available on request from F.S. Univariate differences between the two samples were tested by means of t-tests.

$^{+}0.05 < P < 0.1$; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

[a] Percentage of nesting or random trees covered by ivy. Difference tested by means of a χ^2 test on the count data.

[b] t-test carried out on the variable transformed in the arcsine square root of the proportion.

[c] t-test carried out on the variable square root transformed.

[d] t-test carried out on the variable $\log_e$ transformed.

Table 3. Environmental variables measured at 25 common buzzard tree nests and at 25 trees, each one randomly chosen within a 0.04 circular plot centred on each nest tree (Italian pre-Alps, 1993–2002)

Variable	Nests trees ($n = 25$)	Random trees ($n = 25$)
Dbh[***]	45.4 ± 2.7	20.1 ± 1.4
Tree height[a*]	19.2 ± 0.8	15.6 ± 0.6
Branch height[a]	7.3 ± 1.0	5.6 ± 0.7
Covered by ivy[b**]	36.0	0.0

Univariate differences were tested by means of paired t-test.

$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

[a] t-test carried out on the variable $\log_e$ transformed.

[b] Percentage of trees covered by ivy. Difference tested by means of a χ^2 test on the count data.

reclassified 60% of the nests and 72% of the random cliffs (overall reclassification = 66%). Cliff height was positively correlated with nest height ($r = 0.55$, $n = 25$, $P = 0.008$).

Selection of forest-sites: nest-stand level

Of the 25 measured nests, 24% were on sweet chestnut, 12% on oak species, 12% on Scots pine (*Pinus sylvestris*), 8% on beech and the remaining 44% on other seven tree species. It was impossible to compare such a pattern with the one from random trees by χ^2 analysis because of the high incidence of expected frequencies that were less than 5. When trees were classified as sweet chestnut or not, buzzards were not selective with respect to tree species ($\chi^2 = 2.17$, $P = 0.14$). Of the seven variables tested for model entrance (Table 2), only the percentage of trees covered by ivy (arcsine square-root transformed) entered the stepwise logistic GLM (with binomial errors and a logit link function: Crawley, 1993; $B = 210.4 \pm 134.3$, $\chi^2 = 0.07$, $P = 0.002$; B for constant $= -0.7 \pm 0.4$), which correctly reclassified 76% of the buzzard nests and 88% of the random trees (overall = 82%). The percentage of trees covered by ivy was positively related to mean tree height in the stand ($r = 0.30$, $n = 50$, $P = 0.03$).

Selection of forest-sites: nest-tree level

Univariate, paired comparisons between each nest tree and one random tree in its immediate surroundings (0.04 ha plot) showed that buzzards selected taller trees with a larger diameter at breast height (Table 3). The latter variable was the only one to enter the logistic regression model, which correctly classified 88% of the nests and 92% of the random trees (overall = 90%: $B = 0.31 \pm 0.11$, Wald = 8.20, $P = 0.012$; B for constant $= -8.29 \pm 2.84$).

Comparison between cliff and tree nests

To gain further insight into the process affecting the selection of a tree or a cliff nest, we compared the environmental features that could be collected for both

Table 4. Environmental variables measured at the landscape scale at 40 common buzzard nest-sites and at 40 random sites (Italian pre-Alps, 1993–2002)

Variable	Buzzard nests ($n = 40$)	Random locations ($n = 40$)
% slope[a,**]	13.3 ± 0.8	10.5 ± 0.5
Micro-ruggedness index[a,**]	20.7 ± 1.2	15.8 ± 0.8
Macro-ruggedness index[a,***]	68.0 ± 3.1	51.2 ± 2.1
NND[a,+]	1384.0 ± 106.9	1153.5 ± 98.2
Distance to open[b,**]	151.8 ± 29.0	300.9 ± 32.2
Distance to building[a,*]	510.0 ± 46.0	394.4 ± 40.5
Distance to village[a,*]	770.8 ± 79.1	583.2 ± 74.2
% urban[c,+]	4.1 ± 0.8	8.8 ± 1.9
Interspersion index[b,***]	15.2 ± 0.7	10.9 ± 0.7
Woodland-open interspersion index[**]	5.0 ± 0.6	2.9 ± 0.4

Only significant variables are shown for conciseness of presentation; full table available on request from F.S. Univariate differences between the two samples were tested by means of t-tests.

[+] $0.05 < P < 0.1$; [*] $P < 0.05$; [**] $P < 0.01$; [***] $P < 0.001$.

[a] t-test carried out on the variable $\log_e$ transformed.

[b] t-test carried out on the variable square root transformed.

[c] t-test carried out on the variable transformed in the arcsine square root of the proportion.

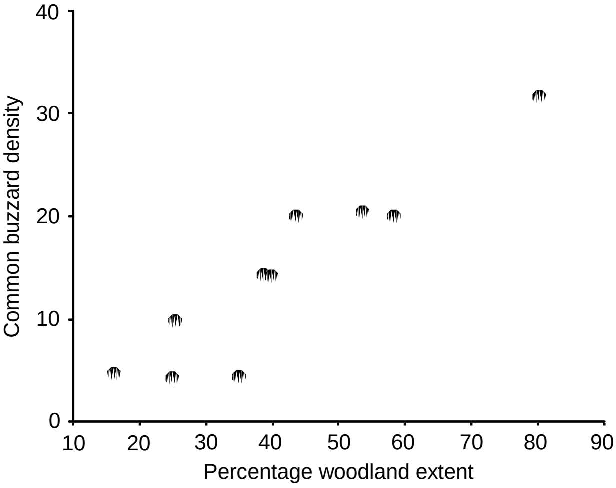

Fig. 2. Population density of common buzzards in relation to percentage extent of woodland in 10 study areas in the Italian pre-Alps (1996–2002).

nest types (Tables 1 and 2). Compared to tree nests, cliff nests were nearer to open areas and had higher values of nest height, micro-ruggedness index, elevation and distance to path and to road (all $t \geq 2.02$, $P < 0.05$). Three of these variables entered a stepwise logistic regression: height of the nest above ground ($\log_e$ transformed, $B = 2.49 \pm 1.15$, Wald $= 4.64$, $P = 0.031$), distance to open areas (square-root transformed, $B = -0.29 \pm 0.10$, Wald $= 8.32$, $P = 0.016$) and distance to road (square-root transformed, $B = 0.36 \pm 0.11$, Wald $= 10.17$, $P = 0.004$). The model correctly reclassified 80% of the cliff nests and 92% of the tree nests (overall = 86%).

Selection of nest-sites: landscape-level

Of the 10 variables tested for model entrance (Table 4), four had access to the logistic model: interspersion index ($B = 0.51 \pm 0.14$, Wald $= 13.2$, $P = 0.0004$), macro-ruggedness index ($\log_e$ transformed, $B = 4.26 \pm 1.70$, Wald $= 6.3$, $P = 0.048$), distance to building ($\log_e$ transformed, $B = 1.90 \pm 0.71$, Wald $= 7.2$, $P = 0.028$) and NND ($\log_e$ transformed, $B = 2.30 \pm 0.83$, Wald $= 7.7$, $P = 0.024$). The model correctly reclassified 82.5% of the nests and 85.0% of the random sites (overall = 83.8%). When validated on the independent data from the Noce area, the model correctly classified 80% out of 20 nests and 75% out of 20 random locations.

Factors affecting breeding performance

Two variables entered a stepwise multiple regression with the number of fledged young per territorial pair as the dependent variable: % heath ($B = 1.80 \pm 0.53$, $t = 3.4$, $P = 0.012$) and % farmland ($B = -7.17 \pm 2.52$, $t = -2.8$, $P = 0.016$; $R^2 = 0.36$). Two variables entered a stepwise multiple regression with the number of young fledged per successful pair as the dependent variable: % heath ($B = 0.59 \pm 0.28$, $t = 2.1$, $P = 0.048$) and % rocky outcrops ($B = 2.17 \pm 0.61$, $t = 3.5$, $P = 0.004$; $R^2 = 0.50$).

Population-level effects

Buzzard density was positively related to the percentage extent of woodland ($r_s = 0.91$, $P = 0.001$: Fig. 2) and negatively related to the density of eagle owls in each area ($r_s = -0.72$, $P = 0.040$).

DISCUSSION

Buzzards were selective at all spatial scales analysed. At the micro-scale, the birds selected features of cliffs and trees that allowed them to position nests high above ground in a concealed location. In particular, many tree-nests were on very mature trees (see also Cerasoli & Penteriani, 1996) fully covered by ivy, so that the nest itself was completely surrounded by ivy and often impossible to see from the ground. Building concealed nests high above ground has been previously reported (Jędrzejewski, Jędrzejewska & Keller, 1988; Hubert, 1993) and is likely to minimise potential predation by human beings and other terrestrial predators. In our area, mammalian nest-predation is scarce, but nest robbing by humans was frequent up until recently (Sergio *et al.*, 2002, 2003*d*). The active avoidance of potential human predation was further suggested by the landscape-level avoidance of roads and may also explain the high frequency of cliff nests (Sergio *et al.*, 2002), which are usually more difficult to access, higher above ground and farther from roads than tree nests. Similar results have been obtained for the sympatric black kite (*Milvus migrans*), suggesting that both species responded to a similar predation pressure, despite selecting different foraging habitats (Sergio *et al*., 2003*d*).

At the landscape-level, buzzards selected rugged areas with a high availability of habitat boundaries and were far from conspecifics. These features were probably related to food availability. Buzzards are opportunistic predators with a varied diet, locally dominated by a few main prey species (Tubbs, 1974). Higher availability of habitat boundaries implies higher habitat heterogeneity, which may allow rapid prey-switching when the availability of any of the main prey declines (Steenhof & Kochert, 1988). Similar results were obtained by Austin *et al*. (1996) in the Scottish uplands. A rugged topography may, in addition, increase habitat heterogeneity, while simultaneously maximising the area effectively available for hunting within a certain radius of the nest (see Penteriani & Faivre, 1997 and McLeod *et al*., 2002 for similar results). Finally, avoidance of conspecifics is to be expected in a solitary nesting raptor with a uniform dispersion of nest-sites (e.g. Sergio, Marchesi & Pedrini, 2004). Such spacing behaviour may allow population density to be fine-tuned on resource availability, while simultaneously minimising intraspecific competition (e.g. Newton, 1979; Village, 1983).

Buzzard productivity was (1) positively related to the availability of arid habitats (rocky outcrops and dry heath), which are rich in snakes (Sergio, 2002), the local main prey and (2) negatively related to farmland availability, which is poor in prey species (Sergio *et al*., 2003*b*). Finally, buzzard density was negatively related to eagle owl abundance and positively related to woodland availability. Eagle owl predation on buzzard adults and nestlings has been frequently reported (Olsson, 1979; Penteriani, 1996; Marchesi *et al*., 2002). We have previously shown that this powerful and aggressive owl may limit the populations of medium-sized raptors (Sergio *et al*., 2003*a*; Sergio, Pedrini & Marchesi, 2003*c*). The positive relationship between woodland availability and buzzard density may also be integral to a strategy of owl avoidance by buzzards through habitat segregation (e.g. Polis & Holt, 1992; Newton, 1998). In fact, eagle owl density usually peaks in very open landscapes and declines with the availability of woodland, which is usually an unsuitable hunting habitat for this large-bodied species (e.g. Sergio *et al*., 2004; Penteriani *et al*., 2001*b*; Penteriani, Gallardo & Roche, 2002). However, it should also be noted that woodland is considered the ancestral habitat of common buzzards (Jędrzejewski *et al*., 1988). Some populations can breed successfully at high densities in very forested regions (Tubbs, 1974; Newton, Davis & Davis, 1982; Gibbons *et al*., 1994) and, in our Lugano study area, almost 70% of 1192 identified food items were of woodland origin. Therefore, the additive effects of low predation risk and other woodland-related advantages, such as higher food or nest-site availability, may have caused the positive effect of woodland on density. In conclusion, buzzard settlement, density and productivity were affected by the complex interplay of food availability, human persecution and predation risk, all of them probably mediated by the availability of safe nest-sites affording ready access to a diverse food supply.

Implications: conservation guidelines

The current conversion of coppice woodland to mature forests is likely to benefit buzzard populations by increasing nest-site availability. Mature forests are also likely to support higher densities of their main prey species than coppice woodland (e.g. small mammals: Gurnell, Hicks & Whitbread, 1992), especially because most of the current coppice is composed of sweet chestnut, which is characterised by an extreme lack of ground flora in the herbaceous and bush layers, leading to a poor faunal assemblage (Fuller, 1992; Gurnell *et al*., 1992; I.P.L.A., 2000). In contrast, land abandonment and the consequent loss of open habitats may disfavour buzzards by decreasing habitat heterogeneity and the availability of dry heath. This habitat is extremely rare in the Alps and typically occurs in areas with igneous rocks, acidic soils and frequent (artificial) burning. Its rarity and rich herpetofauna (unpublished data) makes it an important component of regional biodiversity and it should be actively preserved.

Based on our results, we propose the following guidelines:

(1) The conversion of neglected coppice to mature forest is favoured, but it should be managed through sylvicultural systems to allow the continual availability of mature trees (e.g. Penteriani & Faivre, 2001; Seymour & Hunter, 1999).

(2) Some scattered trees or clumps of trees should be left to grow indefinitely, especially near cliffs, and some woodland patches should be left to be covered by ivy since this is also favoured by other raptors (e.g. Sergio *et al*., 2003*d*) and increases the structural and invertebrate diversity, with minor or no timber loss (Andrews & Rebane, 1994; Broad, 1999).

(3) Ideally, some patches of actively-managed short rotation coppice mainly composed of oak species should be left, so as to increase horizontal and vertical heterogeneity (the early stages of coppiced oak woodland can support high numbers of vertebrate and invertebrate species, e.g. Fuller, 1992; Greatorex-Davies & Marrs, 1992; Gurnell et al., 1992; Fuller & Warren, 1993).

(4) All patches of dry heath should be preserved and subsidies enhanced for their active management through prescribed, controlled burning at least once every 10–20 years (e.g. see prescriptions in Dolmand & Land, 1995).

Such guidelines would simultaneously:

  a. favour buzzards and other raptor species (based on previous results, e.g. Pedrini & Sergio, 2002; Sergio *et al*., 2003*b*,*d*, 2004)
  b. satisfy the needs of the local agro-forestry industry (e.g. by favouring the conversion of neglected coppice to more economically profitable mature forest)

(c) probably benefit broader-scale biodiversity (based on current knowledge, e.g. Sergio, 2002; Sergio & Pedrini, 2004).

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APPENDIX 1. Environmental variables measured at common buzzard nests and random sites (central Italian pre-Alps, 1993–2002)

Variable	Description
Cliff level[a]	*Characteristics of the nesting cliff and its immediate surroundings*
Nest height (m)	Height of the nest above the ground
Cliff height (m)	Height of the cliff
Cliff width (m)	Width of the cliff in the widest portion
Height of cliff complex (m)	Maximum height of the cliff complex
Width of cliff complex (m)	Maximum width of the cliff complex
% vegetation cover	% of the cliff face covered by vegetation
Cliff climbing	Cliff regularly used by cliff-climbers (0) or not (1)
Nest-stand level[a]	*Characteristics of the nest tree and the woodland in its surroundings*
Dbh (cm)	Diameter at breast height of the nest tree
Nest height (m)	Height of the nest above the ground
Branch height (m)	Height of the lowest live branches of the nest tree
Tree height (m)	Height of the nest tree
Covered by ivy	Nest tree covered by ivy (1) or not (0)
Mean dbh (cm)[b]	Mean diameter at breast height in the 0.04 ha plot
Mean tree height (m)[b]	Mean tree height in the 0.04 ha plot
Mean branch height (m)	Mean height of the lowest live branches for trees in the 0.04 ha plot
Tree density[b]	Number of trees/ha in the 0.04 ha plot
% basal area [b]	Total tree basal area expressed as percentage of 0.04 ha
% canopy cover	% of the 0.04 plot under the cover of the canopy
% shrub cover	% of the ground in the 0.04 ha plot covered by shrubs
% live trees	% of the trees in the 0.04 ha plot which are alive
% with ivy	% of trees in the 0.04 ha plot covered by ivy
Tree species richness	Richness of tree species in the 0.04 ha plot
Tree species diversity	Shannon index of diversity of tree species in the 0.04 ha plot
% rocky ground cover	% of the ground in the 0.04 ha plot composed of rocky outcrops
Landscape-level	*Landscape structure and composition within 700 m of the nest*
Elevation (m)	Elevation above sea level (a.s.l.)
% slope	% slope within 100 m of the nest
Micro-ruggedness index	Number of contour lines crossed by two N-S and W-E transects of 200 m
Macro-ruggedness index	Number of contour lines crossed by two N-S and W-E transects of 1.4 km
NND (m)	Nearest neighbour distance
Distance to open (m)	Distance to the nearest open habitat
Distance to cliff (m)	Distance to the nearest cliff
Distance to path (m)	Distance to the nearest path

APPENDIX 1. Continued

Variable	Description
Distance to road (m)	Distance to the nearest asphalted road
Distance to building (m)	Distance to the nearest inhabited building
Distance to village (m)	Distance to the nearest village or town
% woodland [c]	% extent of woodland within 700 m
% shrubs	% extent of shrub-dominated vegetation within 700 m
% heath	% extent of dry heath (mainly dominated by *Calluna vulgaris*) within 700 m
% rocky outcrops	% extent of rocky outcrops within 700 m
% arid	= % shrubs + % heath + % rocky outcrops
% unmanaged grassland	% extent of unmanaged grassland within 700 m
% managed grassland	% extent of cultivated grassland within 700 m
% grassland	= % managed grassland + % unmanaged grassland
% farmland	% extent of intensive farmland (does not include cultivated grassland) within 700 m
% water	% extent of water bodies within 700 m
% urban areas	% extent of urban areas within 700 m
% unmanaged open habitats	= % arid + % unmanaged grassland
% open habitats	= % arid + % grassland + % farmland
Interspersion index	Number of habitat edges crossed by two N-S and W-E transects of 1.4 km crossing each other over the nest or at a random location
Woodland–open interspersion index	Number of edges between woodland and open habitats crossed by two N-S and W-E transects of 1.4 km
Woodland edge length (m)	Length of the edge between woodland and open habitats within 700 m and expressed as length/km^2
Habitat diversity	Shannon index of habitat diversity (Shannon & Wiener, 1949)

[a] Elevation, % slope, micro-ruggedness index and distance to path, road, building and village were also collected at the cliff and nest-stand level.

[b] Also calculated separately for trees in the dbh interval class: <20 cm, 20–40 cm and >40 cm.

[c] Other woodland-variables recorded included the % extent of forest dominated by sweet chestnut, oak, beech, European hop-hornbeam, conifers and their combinations (sweet chestnut + oak, oak + European hop-hornbeam, sweet chestnut + oak + European hop-hornbeam).