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Breeding density and nest site selection in a Goshawk *Accipiter gentilis* population of the Central Apennines (Abruzzo, Italy)

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Information on forest vegetation structure immediately around a Goshawk's nest can indicate the minimum forest stand surface necessary to be conserved or created to favour Goshawk settlement and help solve potential conflicts between timber harvest and maintenance of a viable Goshawk population. In order to gain greater insight into this species and to contribute to a correct policy for managing forests, Goshawk nest site characteristics were examined at three levels of scale (nest/nest trees level, nest site level, landscape level). The breeding density recorded in the study area is 5.03 sites/100 km². The nests were found on north- and east-facing slopes and in the central part of the tree canopy. The average values of crown height and surface diameter at breast height (dbh) were higher than the corresponding values recorded in nest plots. The average values of dbh, tree height, height of trunk without branches, crown height, crown length, crown breadth, crown basal area, crown volume, distance between trunks and plot centre canopy cover were significantly higher in nest plots than in control plots. Some characteristics of the nest site were consistent among nest sites even though analysis of the landscape surrounding the nest site showed a great variety of habitat composition and structure.

Many studies provide evidence that birds respond to vegetation features in selecting their breeding habitats.[1] Studies on Goshawk *Accipiter gentilis* nesting habitat[1–11] indicate a preference for old forest, suggesting that such habitats offer the best conditions for breeding. Few studies have analysed Goshawk habitat selection in Europe, however, and only two studies concern mediterranean regions.[7,11]

The scale and the habitat level of a study define the domain to which its results are applicable. Conservation planning requires both intensive and extensive approaches to data collection.[12] When Goshawk nest sites are studied from a microhabitat perspective (forest structure around the nest), the results can be of practical use only in nest-level forest management. For more wide-ranging conservation planning, additional data are required on habitat use by the species and on the effect of habitat quality on breeding success.[13] Descriptive studies are initially necessary to determine patterns, but they should serve as starting points for developing a more mechanistic understanding of a phenomenon,[13] to increase the predictive ability of models developed for conservation planning. Information concerning structure, composition and stand size of the forest immediately around a nest can be used to recommend preservation of woodland managed for timber production.[9,14,15]

This study was carried out to determine the density of Goshawk populations in a mediterranean mountain area and to characterize the vegetation structure of nest sites, so as to gain greater insight into the species and to contribute to an appropriate policy for forest

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management. Identifying changes, if any, in the structure of forest near Goshawk nests (hopefully those which are important to Goshawks), should help to determine the minimum forest stand surface necessary to be conserved or created to favour Goshawk settlement and to help solve potential conflicts between timber harvest and maintenance of viable Goshawk population.

STUDY AREA AND METHODS

The study was conducted in an area of the Abruzzo portion of the Apennine mountains (Central Italy: 41°49′ N, 13°47′ E): the Abruzzo National Park, the Sirente massif and the Majella massif. The area, with altitudes ranging from 800 to 2300 m above sea level, predominantly consists of beech *Fagus sylvatica* forested slopes, with grazing and fallow farmland at their base. The landscape is often carved by deep rocky valleys. Above 1900 m, forests are replaced by high-altitude pastures.

Breeding density

Goshawk nest sites were identified by a combination of methods, including mapping of all forested areas by aerial photos (1:10 000) and topographic maps (1:25 000), walking visits to woodlands (November to April), observation of nuptial displays and territorial flights (February to April, especially from the second week of March to the first week of April) and playback of taped calls: this method yields the best results during the courtship and nestling periods.[16,17]

Occasionally, nests were traced from plucking, droppings and moulted feathers, adult alarm and nestling calls. For density, the nearest-neighbour distance method was applied.[18] Regularity in nest site spacing was computed with the *G*-test.[19]

Nest site characteristics

The analysis of habitat selection only considered Goshawk nest sites where nests had been accurately identified; moreover, all nesting sites with changes during the study period (e.g. road building, cutting of wide forest tracts, changes in farming areas) were excluded from the landscape analysis. For this reason, only 12 of the 16 nesting sites identified by census were analysed, with a total of 30 different nests: Goshawk nest site characteristics were determined at three scales (further details are given in Table 1).

Nest/nest tree level

This involved analysis of nest trees and nest characteristics.

Nest site level

This involved analysis of circular plots (diameter: 100 m = 0.78 ha) centred on nest trees.[1,8,10,20] The plots contained four transects (along which measurements were made) at 90°, with one end at the centre of the plot and the other at each of the four cardinal points. Tree parameters were measured on the trees intercepted by the paths of the transects, based on the line intercept method.[21] Each plot was further divided into five 10-m-wide concentric rings to investigate possible progressive changes in structural parameters within a radius of 50 m around the nest. The point-centred-quarter method[8,21] and concentric rings were also applied to four control plots centred on the four cardinal points at 150 m from the nest.

Landscape level

This involved analysis of circular plots centred on the geometric centre of polygons formed by lines joining the nests. The plots had a diameter equal to the average nearest-neighbour distance between nest sites. These plots provided a comparison between habitat at nest sites and elsewhere in the area as a whole. The plots had four transects along which number of ecotones, number of habitats and interspersion index[22] (see Table 1) were calculated. The surface areas of the different habitats were determined from 1:25 000 land-use maps. The distance of nest sites from forest edge, valley bottom and surrounding villages, roads and perennial water (assumed as parameters) was also calculated.

Statistics

Data were statistically analysed with descriptive methods for all levels and with multivariate methods for the nest site level.

Multivariate analysis relied on correspondence analysis.[23,a]

Table 1. Habitat and nest-specific variables used to describe Goshawk nest sites: *n*, variable considered for nests, *p*, variable considered for plots inside the nest-site, *n* + *p*, variable considered for nests and plots inside the nest-site, *l*, variable considered for landscape plots.

Variable
n – elevation (m asl)
n – slope exposure
n + *p* – diameter at breast height
n + *p* – circumference at breast height [($dbh^2/2$) × 3.14]
p – total surface dbh (m^2/ha)
n + *p* – tree height (m)
n + *p* – height of trunk without limbs (m)
n – number of nest-supporting branches
n – branches number
n – branches fork number
n – angle (°) between trunk and nest-supporting branches
n + *p* – crown height (m)
n + *p* – crown length (m)
n + *p* – crown breadth (m)
n + *p* – crown basal area (m^2)[a]
n + *p* – crown volume (m^3) [(length/2) × (breadth/2) × 3.14 × (tree height)]
n – nest height (m)
n – % nest height [(nest height/tree height) × 100]
n – nest distance (m) to first, foliage-covered, lower branch
n – nest distance (m) to first dead lower branch
n – nest distance (m) to tree top
n – nest tree distance (m) to nearest ancient coal platform
n – nest tree distance (m) to nearest wood-cutting trail
n – nest tree distance (m) to nearest woods trail
n + *p* – distance between trunks
n – nest position on slope, divided into three layer (upper, central and lower)
n – aerial flight space inside the wood[b]
p – slope gradient (°)
p – tree density (trees number/m^2)
p – foliage abundance (%)[c]
p – plot centre canopy cover (%)[d]
p – canopy cover (%) 25 m away from plot centre[e]
l – number of ecotones[f]
l – number of different habitats[f]
l – area (%) of different habitat patches
l – nest-site distance to wood edge, valley bottom, nearest village, nearest road, permanent water
l – patch interspersion index [(habitat changes/plot area) × 100][f]

[a]The crown basal area is estimated as an ellipse [(length/2) × (breadth/2) × 3.14].
[b]The free volume inside the wood (available and necessary for Goshawk flights near the nest) is assimilated to square based parallelepiped, where major sides are represented by trunks without limbs heights and the basal sides are the distances between trunks.
[c]Three layers:[28] 0–0.7 m, 0.71–7.6 m, > 7.61 m.
[d]Insolation inside the wood[5,28] was determined by calculating the percentage of sky obstructed by vegetation on black and white photos (28 mm lens, f. 3.5) of canopy cover, on a grid with squares of 1 mm^2.
[e]Calculated like a mean of canopy cover in the four transects of each plot.
[f]Calculated on two orthogonal axes from the plot centre.[2,17]

t-tests were used to compare: (a) the average values of nest plot parameters with those of control plot parameters; and (b) the average values of nest plot ring parameters with those of control plot ring parameters. χ^2 was used to test: (a) nest location on the slope (nest/nest tree level); (b) nest exposure (nest/nest tree level); (c) distribution of nest plots in the space bounded by the correspondence analysis axes (nest site level) against a random expectation. The Shannon index quantified habitat diversity of landscape level plots.[24]

RESULTS

Breeding density

A total of 16 Goshawk nesting pairs were identified within a 318 km^2 area, giving a density of 5.03 pairs/100 km^2. Minimum distances between pairs averaged 3.5 km (range 2–4.9 km, sd = 1.02). The value of the *G*-statistic (0.99) indicates a regular distribution of nest sites inside the study area.

Nest characteristics

The nests were found in the following types of location.

a In a relatively wide altitude range, including most of the mountain area occupied by patches of mature beech forest (Table 2).

b On north- and east-facing slopes, with a preference for the north-facing one: N = 8 (26.7%), NNE = 15 (50%), NE = 6 (20%) and ENE = 1 (3.3%) ($\chi^2 = 13.445$, df 3, $P < 0.005$).

c Predominantly in the central tract of the forest; this location is highly significant: upper = 5 (16.6%), central = 23 (76.6%) and lower = 2 (6.8%) ($\chi^2 = 25.8$, df 2, $P < 0.001$).

d Predominantly at two-thirds tree height, i.e. in the central part of the tree canopy, as corroborated by data on: (a) nest distance from the first, foliage-covered, lower branch; (b) height of the tree crown; and (c) nest distance from the tree top (Table 2).

As Goshawk nests are mainly placed at the bottom of the crown, they rest on the largest branches. Since these branches are the most spaced from each other, they provide a wide

Table 2. Characterisitics of nest (n = 30) and nest trees (n =30), compared with nest site plots (n = 30).

	Nests/nest trees		*Nest site plots*		
Variable	x	*sd*	x	*sd*	t-*test*
Elevation (m)	1385.7	95.48			
Nest height (m)	17.4	3.14			
Nest height (%)	69.4	13.11			
Number of nest-supporting branches	5.6	1.69			
Angle of trunk-branches supporting nest (°)	52	10.87			
Number of branches	27.3	9.28			
Number of branch forks	1.9	0.43			
Nest distance to tree top (m)	7.9	3.86			
Nest distance to first foliage-covered branch (m)	5.8	3.64			
Nest distance to first dead lower branch (m)	6.5	3.1			
Nest tree distance to nearest charcoal burning site (m)	12	14.18			
Nest tree distance to nearest wood-cutting trail (m)	37.5	17.08			
Nest tree distance to nearest wood trail (m)	11.2	15.05			
Tree height (m)	25.3	2.98	21	1.96	$t = 10.66$ df = 58 ns
Height of trunk without branches (m)	11	3.7	9.1	2.98	$t = 10.72$ df = 58 ns
Diameter at breast height (m)	0.5	0.1	0.3	0.07	$t = 5.35$ df = 58 $P < 0.05$
Circumference at breast height (m)	0.3	0.08	0.2	0.08	$t = 44.5$ df = 58 $P < 0.05$
Crown height (m)	14.5	2.61	12.4	2.52	$t = 12.78$ df = 58 $P < 0.05$
Crown length (m)	12.3	2.28	8.4	1.18	$t = 5.43$ df = 58 ns
Crown breadth (m)	10.1	1.99	7.1	0.97	$t = 5.68$ df =58 ns
Crown basal area (m^2)	100.3	37.86	47.9	11.05	$t = 2.83$ df = 58 ns
Crown volume (m^3)	1487.6	712.18	595.2	250.59	$t = 2.33$ df = 58 ns
Distance between trunks (m)	6.6	2.58	5.3	0.67	$t = 9.09$ df = 58 ns

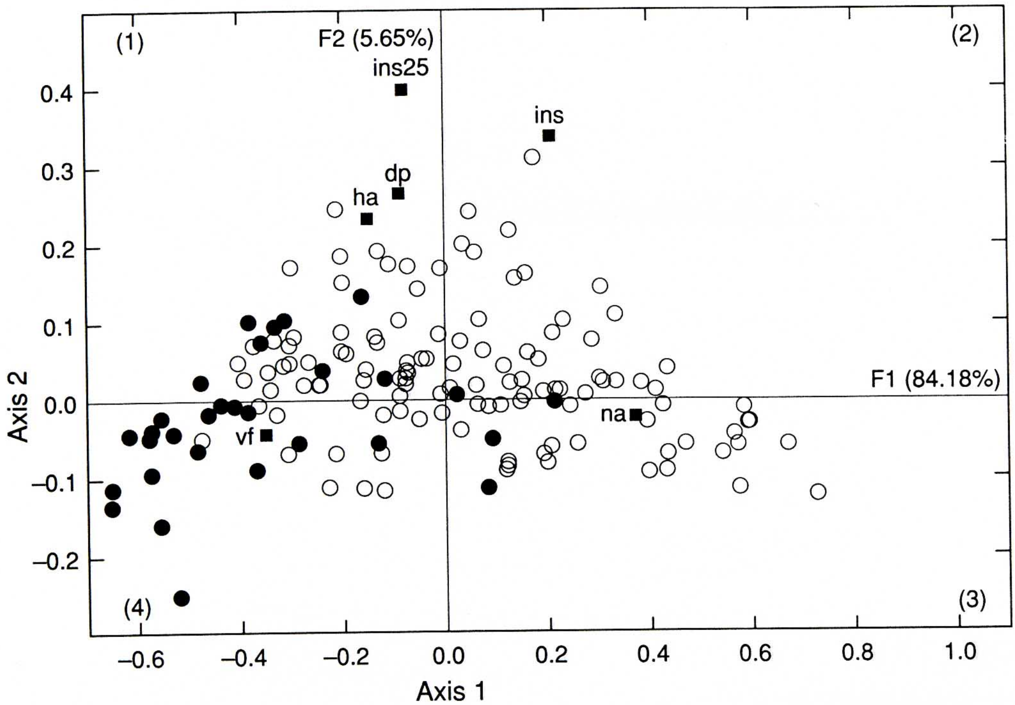

Figure 1. Distribution of the 30 nest-site plots (●) and 120 control plots (○) on the first and second correspondence analysis axes. Only variables with high absolute contributions are represented. Axis 1: na, tree density; vf, volume of tree crowns; Axis 2: ins, canopy cover at the plot centre; ins25, canopy cover at 25 m to plot centre; dp, slope; ha, height of trees.

and stable stand. Trunk and nest-supporting branches tend to intersect at right angles. Nests are built: (a) usually, on the central branches of beeches and against the trunk (n = 23, 76.7%); (b) occasionally, on a lateral branch, but always leaning in part against the trunk (n = 6, 20%); (c) in one case only (3.3%), the nest was built on a branch away from the trunk.

Nest site characteristics

The 16 variables used to analyse nest site characteristics (Table 1) were tested with correspondence analysis. The first two axes of the correspondence analysis (Fig. 1) explain 89.8% of the variance. The first axis (84.2% of the variance) denotes crown volume and tree number; the second axis refers to tree height, plot centre canopy cover, canopy cover 25 m away from plot centre and degrees of slope gradient. Nest plots are dispersed in a significantly non-random way on the axis-bounded quadrants (Table 3), stressing that Goshawks preferred forested gentle slopes, low density of trees and poor insolation, with huge trees of high crown volume.

A comparison of parameters in nest site plots and in nest trees (Table 2) indicates that: (a) the average values of crown height and surface diameter at breast height (dbh) are significantly higher than the corresponding values recorded in nest plots; and (b) the average plot centre canopy cover has a significantly lower value in

Table 3. Correspondence analysis: significance level of nest-site distribution on axial spaces.

Axis-bounded quadrants	1	2	3	4
Nest number	8	2	2	18
	χ^2= 22.8 (df = 3) P < 0.001			

Axis-bounded quadrants	1 + 4	2 + 3
Nest number	26	4
	χ^2 = 16.13 (df = 1) P < 0.0001	

Axis-bounded quadrants	1 + 2	3 + 4
Nest number	10	20
	χ^2 = 3.33 (df = 1) P > 0.05	

Table 4. Characteristics of nest site plots (n = 30), compared to control plots (n = 120).

Variable	*Nest site plots* x	*Nest site plots* *sd*	*Control plots* x	*Control plots* *sd*	t-*test*
Tree height	21	1.96	18.2	2.9	t = – 4.84 df = 148 P < 0.001
Trunk without branches height	9.1	2.98	7.3	1.55	t = – 4.44 df = 148 P < 0.001
Diameter at breast height	0.3	0.07	0.2	0.06	t = – 5.05 df = 148 P < 0.001
Circumference at breast height	0.2	0.08	0.1	0.05	t = – 5.35 df = 148 P < 0.001
Total circumference at breast height	2.4	1.18	1.44	0.75	t = – 5.35 df = 148 P < 0.001
Crown height	12.4	2.52	10.8	2.14	t = – 3.63 df = 148 P < 0.001
Crown length	8.4	1.18	6.8	1.05	t = – 7.41 df = 148 P < 0.001
Crown breadth	7.1	0.97	5.7	0.92	t = – 7.44 df = 148 P < 0.001
Crown basal area	47.9	11.05	30.9	6.86	t = –10.63 df = 148 P < 0.001
Crown volume	595.2	250.59	337.9	109.89	t = – 8.49 df = 148 P < 0.001
Distance between trunks	5.3	0.67	4.3	0.84	t = – 5.97 df = 148 P < 0.001
Tree density	0.03	0.02	0.06	0.03	t = – 3.38 df = 148 P < 0.001
Plot centre canopy cover	7.9	3.38	10.5	8.33	t = 212 df = 148 P < 0.05
Canopy cover 25 m away from plot centre	7.9	3.82	9.6	5.77	t = 1.49 df = 148 ns
Slope gradient	15.3	4.12	15.5	3.37	t = 0.29 df = 148 ns

nest trees. Comparative analysis of parameters of Goshawk nest site plots and control plots (Table 4) indicated that: (a) the average values of dbh, tree height, trunk without branches height, crown height, crown length, crown breadth, crown basal area, crown volume, distance between trunks and plot centre canopy cover are significantly higher in nest plots; and the average value of tree density is significantly lower in nest plots.

Consideration of flight space available to the birds showed that the internal forest volume is

Table 5. Comparision between variable means of nest-site plots (n = 30) and control plots (n = 120), divided in concentric rings (1–5).

Variable	*Nest-site plots* x	*Nest-site plots* *sd*	*Control plots* x	*Control plots* *sd*	t-*test*
Diameter at breast height					
Ring 1	0.37	0.09	0.27	0.09	t = –5.316 df = 148 P < 0.001
Ring 2	0.33	0.07	0.26	0.09	t = –3.777 df = 148 P < 0.001
Ring 3	0.32	0.08	0.26	0.07	t = –3.7 df = 148 P < 0.001
Ring 4	0.31	0.09	0.23	0.08	t = –4.668 df = 148 P < 0.001
Ring 5	0.28	0.09	0.26	0.08	t = –1.689 df = 148 ns
Trunk without limbs height					
Ring 1	10.79	5.98	6.36	3.24	t = –5.522 df = 148 P < 0.001
Ring 2	9.94	4.49	7.97	3.3	t = –2.706 df = 148 P < 0.01
Ring 3	9.7	3.93	8.87	4.7	t = –0.899 df = 148 ns
Ring 4	8.77	4.25	7.15	2.41	t = –2.768 df = 148 P < 0.01
Ring 5	6.88	2.91	6.6	2.32	t = –0.558 df = 148 ns
Slope gradient					
Ring 1	13.45	5.56	15.57	5.27	t = 1.951 df = 148 ns
Ring 2	15.1	4.47	15.35	3.61	t = 0.328 df = 148 ns
Ring 3	15.62	4.04	15.59	4.1	t = –0.017 df = 148 ns
Ring 4	15.74	4.46	15.37	4.47	t = –0.409 df = 148 ns
Ring 5	16.48	5.18	15.62	4.78	t = –0.861 df = 148 ns

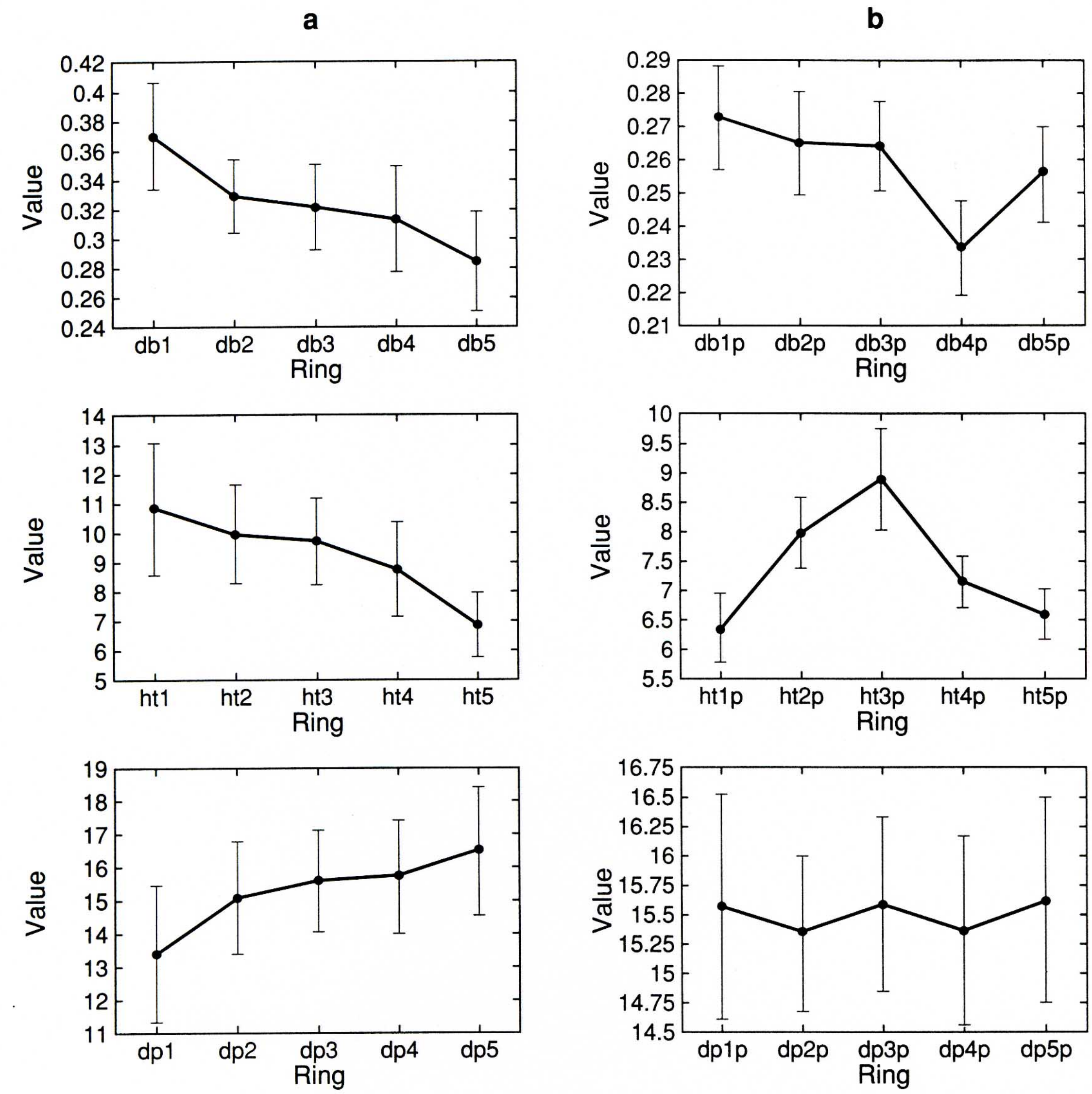

Figure 2. Variation of diameter at breast height (db), height of trunk without limbs (ht) and slope (dp) in the five concentric rings of nest-site plots (a) and control plots (b). Confidence intervals at 95%.

higher in nest plots (min. = 73.6; max. = 803.6; x = 258.31) than in control plots (min. = 24.37; max. = 493.79; x = 138.81), but this difference is not statistically significant (t-test = 3.3, P = ns).

Some parameters of nest site level have constant trends in nest sites, away from nests: dbh decreases, height of trunk without limbs decreases, slope gradient increases (Table 5, Fig. 2).

Landscape analysis

The landscape surrounding Goshawk nest sites consists predominantly of woodlands (mean 60.9 ± 15.34%, range 36.0–88.5%, n = 12) and subordinately of grazing (mean 23.6 ± 12.29%, range 4.9–37.8%) and fallow land (mean 8.6 ± 7.05%, range 0–20.5%), as well as of erosion areas (mean 4.0 ± 6.32%, range 0–18.6%). The Shannon index was computed for each site to assess structural diversity of the landscape. It revealed considerable variation among nest sites (min. = 0.8; max. = 2.16; x = 1.33; var = 0.14; sd = 0.38). The number of ecotones in the plots of the different nest sites has a wide range (mean 48.2 ± 22.31, range 23.0–93.0) and a statistically significant difference in values ($\chi^2 = 100.5$; df = 11; $P < 0.001$), which substantiates the relative structural diversity of the landscape. Also the number of different environments in the plots has a wide range (mean 8.1 ± 1.93, range 5–11) but the difference is not statistically significant ($\chi^2 = 5.05$; df = 11; ns). The interspersion index, used to characterize the landscape structurally, yielded extremely variable values between sites (mean 2.0 ± 0.85, range 0.9–3.3).

Distance between nest sites and forest edges (overlooking open areas) is very variable but rather high (mean 458 ± 223.4m, range 200–850m). Nest sites are always far from possible disturbances, as demonstrated by long distance (m) from valley bottom (mean 2100 ± 714.9, range 800–2900), built-up areas (mean 3304 ± 1658.4, range 900–7800) and surfaced roads (mean 1650 ± 932.3, range 450–3350). Distance from perennial waters is very variable (mean 1291.7 ± 970.9, range 150–3150 m).

DISCUSSION

Density

The survey of nest sites in the study area of the Abruzzo Apennines demonstrated that Goshawk distribution was very regular and was typical of this species. The breeding density of 5.03 km^2 approached values reported from Finland[25] (5 pairs/100 km^2), Germany[26,27,28] (4.5 pairs/100 km^2, 4.7 pairs/100 km^2, 5.5 pairs/100 km^2) and Switzerland[29] (4.4 pairs/100 km^2).

Nest site selection

Nest site selection analysis showed that Goshawks prefer the central tract of a forested area (in a wide spectrum of forest habitats). This tract extends from at least 200 m from the forest edge (the study area has beech-covered slopes starting from an altitude of about 1000 m) to 1550 m of altitude. These data imply that Goshawks settle in the innermost areas of a forest, relatively far from the forest edge and from disturbances, as observed also by Speiser and Bosakowski[10] and Kostrzewa.[6] The preference for dense forest mixed with wide, open areas vital as hunting grounds[30,31] with nests placed relatively far from the forest edge, was reported also by Kostrzewa[6] and Zanghellini & Fasola.[11]

Goshawks prefer north and east slope exposures,[5,7,8,10,11,32] perhaps because they offer the best climate conditions for the growth of beech forests, duration and daylength, as well as temperature. Apart from the strong support given by large branches, the position of nests at the canopy base may also be justified by the fact that Goshawks usually approach and leave the nest flying among the trunks, below the tree canopy. This is supported by the fact that trunks closer to the nest tend to have the largest spacing, so increasing the available flying range in the forest. Moreover, the nest tree is often located close to flight corridors such as footpaths.

Correspondence analysis shows that Goshawks select a nest site stand in the forest which differs from surrounding areas, as observed elsewhere.[1,5,7,10,11] Stand trees here have a high crown volume: this parameter depends on height, length and width of the crown; stand trees have a considerable height; this parameter is in turn related to trunk diameter and basal area; the density of trees is lower than elsewhere; insolation is lower than elsewhere. All these components contribute to characterize Goshawk nest sites and are connected with the developmental stage of the forest, whose parameters reveal its maturity. Hence, such parameters as branchless-trunk height (increasing with tree height) and trunk spacing (increasing when tree density diminishes) contribute to selection of the nest-site as has been reported elsewhere.[1,5,7,10,11]

While slope gradient does not differ in a statistically significant way between nest plots and control plots, it discloses a preference for gentle slopes, especially in the proximity of the nest. This finding was also reported by others,[1,5,8,10] and may be due to the fact that structurally similar sites but with different slope gradient may differ in the availability of flight space.

The high leaf volume of the nest-tree crown may play a crucial role in protecting the brood from excessive insolation[33] and in disguising the large nest from predators.[8] Moreover, nest location in the lower part of the crown ensures a dense leaf roof which guards the nest from overhead predators. Also the gentle slopes of nest sites may reduce the amount of solar radiation on the nest; nests are placed on the least exposed tree, consequently shaded by surrounding trees. Analysis of the internal forest structure revealed that, starting from the nest tree with the highest values of each parameter, all the parameters (except for insolation and slope gradient) fall significantly. Hence, the nest tree may represent a landmark of the forest, the focus of the overall structural system of the nest site, from which size and distinctive features decrease with distance from the nest: maximum, average and minimum control plot values always lie below the corresponding values of nest tree plots (except for trunk spacing and insolation). The nest is placed inside the most mature tract of a high forest which lies inside a less mature tract.

Analysis of the landscape surrounding the nest site showed a large variety of habitat composition and structure, as demonstrated by the wide variation in environmental parameters (number of ecotones, interspersion index), of habitat abundance percentages and of results from the application of the Shannon index for habitat composition. Most of the territory under study consists of forest in which the percentages of abundance are similar to those reported by Hall[5] and Zangnellini and Fasola,[11] with dominance of coppice compared with high forest. In areas with sparse high forest, nest placement only in the most mature portions of the forest and high nest site selectivity are supposed to be the key determinants of Goshawk settlement. Conservation or creation of high-tree forest stands (minimum surface area: 1 ha) on northeast-facing slopes, spaced on the basis of the minimum average distance between the breeding pairs, may be a crucial element for conservation of the species. The components of the surrounding landscape may instead be important for breeding. This finding may explain the high variability of habitat components in landscape-level plots: the species is adaptable (some reports show that Goshawks use their hunting grounds in an opportunistic way[9]) and take a wide variety of prey.

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ENDNOTES

a. Correspondence analysis uses a scaled data matrix derived from tables of counts (contingency tables), such as the presence or absence of species: the outcome of this method is the calculation of loadings for both the observations (individuals) and the variables on equivalent scales, which are then plotted together. Data are converted to proportions or estimates of probabilities and then scaled by a form of simultaneous row and column standardization; the scaled matrix is used to form association matrices, which are then analysed by standard eigenvalue and eigenvector routines following principal components analysis procedure. The eigenvectors of the matrices are scaled to have the same units, to permit plotting the loadings on one graph.

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