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Breeding habitat preferences of the Eurasian sparrowhawk (*Accipiter nisus*) in the foothills of the Šumava Mountains

Bachelor thesis

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Annotation

Breeding habitat preferences of the Eurasian sparrowhawk (*Accipiter nisus*) in a rural area were studied. Spatial distribution and topographical positions of sparrowhawk nests were examined. Vegetation characteristics around nests and random points were recorded and compared. Food supply around nests and random points was assessed and compared. Sparrowhawks' foraging preferences were examined.

I hereby declare that I am the author of this qualification thesis and that I have written it using only the sources listed in the reference list.

České Budějovice, 28 November 2022.

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Tomáš Dvořák

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Abstract

The Eurasian sparrowhawk (*Accipiter nisus*) is a forest dwelling raptorial bird. This study describes its breeding habitat preferences and identifies factors influencing its breeding habitat selection at different spatial scales in a rural area. Habitat characteristics of breeding areas were gathered and compared to randomly selected places. Information on sparrowhawk diet was collected and compared to the food supply. Sparrowhawk nests were regularly distributed within forests of the study area avoiding small forest patches. Sparrowhawk territories were linked to somewhat dense forest stands of distinctive structure. All the sparrowhawk nests were built in coniferous trees, in the lower parts of their green crowns, close to their trunks. Sparrowhawks seemed to prefer localities with higher abundances of some bird species and higher diversity of birds. Sparrowhawks did not prey upon individual bird species proportionally to their abundance in the food supply. These results suggest an effect of intraspecific competition on sparrowhawks' breeding habitat selection and their tendency to conceal their nests. They also suggest that it may be beneficial for sparrowhawks to breed in localities with better food supply and to focus their hunting effort on some bird species more intensively.

Keywords: *Accipiter nisus*, breeding habitat preference, breeding habitat selection

Contents

1 Introduction

Habitat preferences are regarded as unequal use of resources resulting from habitat selection (Hall et al. 1997). Habitat selection is a hierarchical process by which animals choose resources and conditions according to their needs (Johnson 1980). This process is exercised by individuals at multiple spatial and temporal scales, and different resources are selected at different spatial and temporal scales (Johnson 1980, Mayor et al. 2009).

Habitat selection is influenced by many factors (Jones 2001, Kristan et al. 2007). Some factors affect habitat selection via their effect on needs of an individual (e.g. biology and life history of a given species). Other factors may influence habitat availability, e.g. intraspecific and interspecific competition (Carrete et al. 2005, Devries et al. 2018), ability of an individual to perceive habitat heterogeneity and to reach needed resources (Doligez & Boulinier 2008), and predation risk (Coleman & Hill 2014). Habitat selection has direct impact on fitness and survival of individuals and species diversity (Cody 1985, Kristan et al. 2007).

The increased mobility allows birds to prospect available habitats and to choose a habitat for a specific need (Cody 1985). For breeding, habitats should mainly include sufficient food resources, suitable nesting sites, available mating partners and protection against predators (Cody 1985, Doligez & Boulinier 2008, Barea 2012). Breeding habitat selection likely affects reproductive performance. Therefore, selection of habitats of the best available quality for breeding may be beneficial (Cody 1985, Doligez & Boulinier 2008, Chalfoun & Schmidt 2012, Devries et al. 2018). The information on habitat quality is often limited, so the habitat choice is usually based on obtainable cues indicating habitat quality (e.g. vegetation type and structure, presence of suitable sites for building nests, vocalization indicating presence of potential mating partners) and on experience of an individual (Kristan et al. 2007, Chalfoun & Schmidt 2012). Generally, these cues may be obtained via an individual's own experience, forming personal information, or by observing other individuals, i.e. public information (Valone & Templeton 2002, Doligez & Boulinier 2008). The personal information likely influencing breeding habitat selection may be based on imprinting (Stamps & Davis 2006) and on the success of an individual's previous nesting attempts (Chalfoun & Schmidt 2012). Imprinting of cues based on important features of the natal habitat can serve as a basis for further breeding habitat selection (Stamps & Davis 2006). A successful breeding attempt may induce fidelity to the used breeding habitat or even to the actual breeding site. Conversely, a failed breeding attempt can cause abandonment of a breeding site and may help to adjust subsequent choices of breeding habitat (Chalfoun & Schmidt 2012, Ponchon et al. 2017). The public information usually consists of cues indicating conspecifics' breeding performance, e.g. quantity of fledglings (Doligez et al. 2002, Danchin et al. 2004), or their presence in a given habitat, e.g. conspecific song (Hahn & Silverman 2006). Habitats used by successful breeders (Doligez et al. 2002, Chalfoun & Schmidt 2012) or merely occupied by conspecifics (Muller et al. 1997, Hahn & Silverman 2006) may be more attractive to other individuals.

To conclude, breeding habitat preferences are likely adaptive (i.e. reproduction is more successful in preferred habitats) and under selective pressures (Martin 1998, Doligez & Boulinier 2008, Jedlikowski & Brambilla 2017). Therefore, habitats preferred for breeding are likely comprised of the favourable combination of resources and conditions for reproduction by a given species in a given environment and time period.

Breeding habitat preferences of the Eurasian sparrowhawk (*Accipiter nisus*) were studied in different parts of Europe (e.g. Newton 1986, Fasola & Zanghellini 1993, Selås 1996). In Czechia, sparrowhawks' breeding habitat in rural environment was described with particular attention to reporting methodology of searching for sparrowhawk nests (Diviš 2018), and it was also studied in a novel ecosystem of spoil heaps (Šálek et al. 2010).

The aim of this study is to contribute to the knowledge of the ecology of the Eurasian sparrowhawk in a Czech rural area by describing breeding habitat preferences of this species and identifying factors influencing breeding habitat selection at different spatial scales. To address these objectives, following hypotheses were tested: (1) sparrowhawks prefer to breed as far away from each other as possible forming regular distribution, (2) sparrowhawks prefer to place their nests at lower than average altitude in local topography, (3) sparrowhawks prefer large forests for breeding and larger proportions of specific type of forest within their home ranges, (4) sparrowhawks prefer forest stands of specific structure for their territories, (5) sparrowhawks prefer coniferous trees larger than average within their territories for building their nests, and they prefer to build their nests in the lower parts of the green crowns of the nest trees, (6) sparrowhawks prefer to breed in localities with higher abundance and diversity of birds, and they prefer to hunt some bird species more intensively than others in relation to their representation in the food supply.

2 Methods

2.1 Study species

The Eurasian sparrowhawk is a small raptorial bird occurring in almost entire Europe and Temperate Asia. It inhabits primarily woodland areas at all altitudes from the sea level to the treeline (Cramp 1980, del Hoyo et al. 1994), but it also occupies cities (Biaduń 2006, Papp 2011, Schütz & Schulze 2018). Sparrowhawk nests are usually regularly distributed within an area of continuous suitable habitat, and they may be positioned at lower points in the local topography (Newton 1986). Sparrowhawks tend to choose extensive forests for breeding. Smaller woodland patches are used only when larger forests are scarce (Newton 1986). Sparrowhawk nests are typically positioned in forest stands of specific structure (Newton 1986, Fasola & Zanghellini 1993, Selås1996, Diviš 2018). Various tree species may be used as nest trees, although coniferous trees are often favoured (Cramp 1980, Newton 1986, del Hoyo et al. 1994). Sparrowhawk diet consists mostly of birds (Cramp 1980, Newton 1986, Selås 1993, Zawadzka & Zawadzki 2001, Bujoczek & Ciach 2009). Hence, abundance of birds influences spacing and densities of breeding sparrowhawks (Newton et al. 1986) and it may also affect sparrowhawks' selection of breeding habitat. Sparrowhawks usually do not prey upon individual bird species randomly, but they tend to hunt some species more frequently than others (Götmark & Post 1996, Rytkönen et al. 1998).

2.2 Study area

The study was conducted within a 330 km^2 area in southern Bohemia, Czechia (48.72N, 14.18E, Fig. S1). The study area was situated in the foothills of the Šumava Mountains at 500 – 1200 m altitude above sea level, and it was bordered to the east, south and also almost entirely to the west by the Vltava River and the Lipno Reservoir. The terrain was hilly, usually with moderate slopes and shallow valleys.

The land cover consisted of agricultural areas (49.4%), forest areas (46.1%), semi-natural areas (2.0%), artificial surfaces (1.7%), wetlands (0.4%) and water bodies (0.4%, CORINE Land Cover 2018 provided by EEA, Fig. S1). The agricultural areas consisted mostly of pastures and mown meadows along with a few crop fields. The forest areas included coniferous (89%), mixed (10%) and broad-leaved (1%) forests. Main coniferous species were the Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), European silver fir (*Abies alba*) and European larch (*Larix decidua*). Broad-leaved species included mostly the European beech (*Fagus sylvatica*), silver birch (*Betula pendula*), sycamore (*Acer pseudoplatanus*), European ash (*Fraxinus excelsior*), European oak (*Quercus robur*), aspen (*Populus tremula*), alders (*Alnus glutinosa* and *Alnus incana*) and willows (*Salix* spp.). Forests were of varying sizes ranging from small patches (smaller than 1 ha) to extensive areas of continuous woodland covering more than 20 km^2, and they were regularly distributed throughout the study area. Furthermore, the vast majority of forests were managed, i.e. usually planted in patches of monoculture of high densities and subsequently thinned several times. This management resulted in forest stands consisting of tall trees with living branches on only about the higher half or the highest third of their trunks and in overall somewhat homogenous forests, especially on a large scale. The semi-natural areas comprised natural grasslands and transitional woodland-shrub areas with shrubs including mainly the common hazel (*Corylus avellana*), blackthorn (*Prunus spinosa*) and grey willow (*Salix cinerea*). The artificial surfaces consisted mostly of villages scattered over the study area and several small towns. The wetlands comprised peat bogs and inland marshes. The water bodies included several ponds and small streams.

2.3 Spatial scales

To collect data on inherently multiple-scale patterns of habitat preferences, three concentric spatial scales were selected: (1) home range scale (a 1 km radius around a nest), (2) territory scale (a 25 m radius around a nest) and (3) a nest tree. Since the actual sizes of home ranges (i.e. breeding pairs' whole movement ranges) and territories (i.e. defended areas around nests) within the study area were unknown, the selection of home range and territory scales sizes was based on literature information and field observations. Sizes of sparrowhawk home ranges vary in different areas, probably due to differences in land productivity (influencing the food supply), across different periods of a breeding season and also between the sexes (Marquiss & Newton 1982, Selås & Rafoss 1999). During the breeding season, sparrowhawks tend to range further from their nests in areas with poor land productivity and later in the season (i.e. during the late nestling and post fledging periods). Moreover, females generally range further than males, except while laying and incubating eggs or brooding young nestlings. Travelled distances by breeding sparrowhawks from their nests vary widely among different areas (Marquiss & Newton 1982, Selås & Rafoss 1999). However, even in areas with high land productivity and rich food supply, sparrowhawks tend to range about 1 km from their nests in late breeding season periods (Marquiss & Newton 1982). The radius of the home range scale was, therefore, selected to choose an area which may have likely been a part of an actual home range of both sexes regardless of the unknown state of the land productivity in the study area, whilst avoiding inclusion of potentially unused areas. The radius of the territory scale was selected on the basis of findings of numerous signs of sparrowhawk activity (e.g. droppings, pellets, plucking sites) within close surroundings of the nests.

2.4 Data collection

2.4.1 *Nests survey and creation of random points*

The study was conducted during breeding seasons 2020, 2021 and 2022. During each breeding season, a proportion of forests within the study area was searched in order to find as many sparrowhawk territories and active nests as possible. Forests were searched on foot for signs of the sparrowhawks' presence such as plucking sites, droppings, pellets, moulted feathers and nests according to Newton (1986) or Diviš (2018). In some cases, behavioural signs (e.g. building a new nest by a male, vocalization) helping to identify territories were observed. Only new nests were counted including unfinished nests within the territories where no other new nests were built, suggesting failure of a breeding attempt early in the season. Searching was executed from late February to approximately the half of May.

To compare habitat characteristics of used areas with unused places, random points were created. After the final number of nests was found (at the end of April 2022), random points ($n = 15$) were created within forest areas at the distance of at least 1 km from the nearest known sparrowhawk nest and from each other (Fig. S2). The distance was based on a finding of two active nests in the study area approximately 1 km apart from each other. For the creation of random points, ArcGIS Pro software and land cover data (CORINE Land Cover 2018) were used.

2.4.2 Forest structure and other characteristics at different spatial scales

At the home range scale, percentages of the area covered by different categories of land cover (CORINE Land Cover 2018) were calculated. Furthermore, percentages of forests within the area regarding tree species composition, age structure and tree density were calculated using detailed data on forests provided by the Forest Management Institute (FMI 2019). The tree species composition was described by categories quantifying contribution of each tree species within each category (e.g. 70 – 89.9% of spruce with 10 – 29.9% of pine, 50 – 69.9% of pine with 30 – 49.9% of larch). The age structure was described by categories of age in which each category included trees within the range of ten years (e.g. age of trees 1 – 10 years, age of trees 11 – 20 years). The tree density was a relative measure characterized by ten categories indicating the extent of use of the available space by trees (e.g. tree density 10 indicated that 10% of the available space was used by trees, tree density 20 indicated that 20% of the space was used). Additionally, mean altitude within this area was calculated using altitude data (Digital Terrain Model of the Czech Republic of the 5th generation) provided by Czech Office for Surveying, Mapping and Cadastre (ČÚZK) updated on 1 September 2020 with information updated on 16 May 2022.

At the territory scale, tree layer and shrub layer cover was estimated, tree species composition was identified and other variables, namely slope, geographic orientation of a slope, number of trunks, mean distance between trunks and mean diameter at breast height (DBH) of trunks were measured. Moreover, percentages of the area covered by forest stands of particular tree species composition, age structure and tree density were calculated using the same data on forests described above.

For each nest, location of a nest and altitude were recorded using a GPS (Garmin GPSMAP 64sx), the species of a nest tree was identified and following measurements were taken: distance of a nest tree to the nearest forest margin (m), DBH (m), minimum height of branches (m), minimum height of living branches (m), tree height (m) and nest height (m).

2.4.3 Food supply

The abundance of birds was assessed using the point counts method (Dawson 1981). Five counting points were selected at the minimum distance of 200 m from each other within a 1 km radius around each nest and random point. Counting points were selected at sites with vegetation potentially providing cover to hunting sparrowhawks (e.g. forests, forest margins, shrubs). At each counting point, all the birds seen or heard within a 10 min period were recorded, excluding too large species for sparrowhawks to regularly hunt, i.e. species larger than wood pigeons (*Columba palumbus*) according to Newton & Marquiss (1982). Counting was conducted in suitable weather conditions (no precipitation or strong wind), in the morning (6:00 – 11:00 a.m.), twice at each counting point (May - June) in the breeding season when corresponding nests were found (2020 – 2022) and random points selected (2022). For each counting point, two rounds of bird monitoring were executed with a gap of about two to three weeks between the two consecutive counts at each point.

2.4.4 Foraging preferences

To assess potential preference for some bird species as prey, remains of prey items likely consumed by sparrowhawks were collected. Only fresh and semi-fresh plucked feathers, which were readily distinguishable (up to several weeks old), were counted, avoiding bony remains as another resource of information on sparrowhawk diet potentially involving bias, due to complete consumption of small birds leaving no bones and causing prevalence of bones from larger species in bony remains (Newton 1986). Because of the presence of the northern goshawk (*Accipiter gentilis*) in the study area, only plucked feathers found under quite dense forest stands and up to 500 m from a sparrowhawk nest were included. The reason was that sparrowhawks tend to seek cover when plucking their prey probably to avoid being robbed by larger birds, whilst goshawks generally pluck their prey in more open forest stands (Newton 1986).

2.5 Statistical analyses

The pattern of spatial distribution of the sparrowhawk nests within the study area was assessed using an average nearest neighbour statistic in ArcGIS pro (ESRI). Altitudes of the nests were compared with mean altitudes within their surroundings using a Wilcoxon matched pairs test in Statistica 13.5 software (TIBCO Software Inc. 2017).

Differences in habitat characteristics (i.e. vegetation characteristics, food supply) associated with buffers around sparrowhawk nests and random points (i.e. dependent variable or primary predictor) were calculated using variance partitioning by principal coordinate analysis of neighbour matrices (PCNM) in Canoco 5 software (Ter Braak & Šmilauer 2018), which was recommended by Marrot et al. (2015). This multivariate analysis enabled us to remove the effect of geographical position (i.e. space predictors) from the effect of primary predictors (Legendre & Legendre 2012). The analysis is suitable for calculating inter-correlated variables since all these variables enter the analysis simultaneously. The analysis included nine steps: (1) primary predictor test (i.e. preliminary test of the overall effect of primary predictors on the dataset), (2) primary predictor testing by partial redundancy analysis (RDA) based on partial Monte-Carlo permutation tests (n = 499 permutations), (3) principal coordinate analysis (PCoA) based on Euclidean distances (i.e. finding the main space predictors based on GPS coordinates), (4) PCNM for all predictors (i.e. preliminary test of the overall effect of space predictors on the dataset), (5) PCNM selection (i.e. the choice of space predictors based on coordinates using forward selection and partial Monte-Carlo permutation tests), (6) spatial effects analysis (i.e. assessing the amount of variability explained by space predictors), (7) primary predictor effects analysis (i.e. assessing the amount of variability explained by primary predictors), (8) joint effects analysis (i.e. assessing the amount of variability explained by both predictor types) and (9) removal of spatial effects (Šmilauer & Lepš 2014). Three PCNM analyses were performed. The first PCNM analysis was performed for habitat characteristics (land cover, tree species composition, age structure and tree density of forests) within the buffer of a 1 km radius. The second PCNM analysis was performed using habitat characteristics as independent variables within the buffer of a 25 m radius including tree and shrub layers cover, tree species composition, age of trees, tree density, number of trunks, mean distance between trunks, mean DBH of trunks and slope. The third PCNM analysis was performed with food supply, namely maximal abundances of bird species recorded during the survey of food supply (Table S1) and the Shannon index of bird diversity as independent variables. For these analyses, the buffers around the nests/random points were used as dependent variables. Percentage data were arcsine transformed.

Based on the results of PCNM analyses, Mann-Whitney U tests for the differences in vegetation characteristics and components of food supply that were apparently correlated with surroundings of nests and random points were performed using Statistica 13.5 software.

DBHs of the nest trees were compared with mean DBHs of trees around corresponding nests using a Wilcoxon matched pairs test in Statistica 13.5 software.

Foraging preferences for individual prey species were analysed by comparing percentages of bird species recorded in food supply and found among prey remains using compositional analysis of habitat use (function compana from adehabitatHS package) in R 4.0.3 software (R Core Team 2020). Zero values were replaced by 0.01 (Aebischer et al. 1993). A data unit was represented by each buffer around the nests. For each nest, percentages of each habitat category available (proportion of each bird species in food supply) were computed. This analysis was carried out in two steps. Firstly, the significance of habitat use was tested using a Wilks lambda. Secondly, a ranking matrix was built, indicating whether the habitat category in the rows was significantly used more or less than the habitat category in the columns. Furthermore, habitats were sorted from most preferred to non-preferred (Aebischer et al. 1993).

3 Results

The total number of 35 nests was found during the study period (13 nests in 2020, 15 in 2021 and 7 in 2022). The nests were located within forests at altitudes from 572 to 866 m a.s.l. and they were regularly dispersed within the study area (average nearest neighbour, $z = 4.145$, $p < 0.001$, Fig. 1). No significant difference was found between altitudes of the nests and mean altitudes within their surroundings. Forests where the nests were placed varied greatly in size (range = 0.23 – 41.31 km^2; mean ± SD, 14.54 ± 17.81 km^2). However, no nest was placed within relatively small forest areas (smaller than 23 ha). The nests were positioned at varying distances from the nearest forest margin (range = 43.00 – 629.00 m; mean ± SD, 197.63 ± 141.43 m).

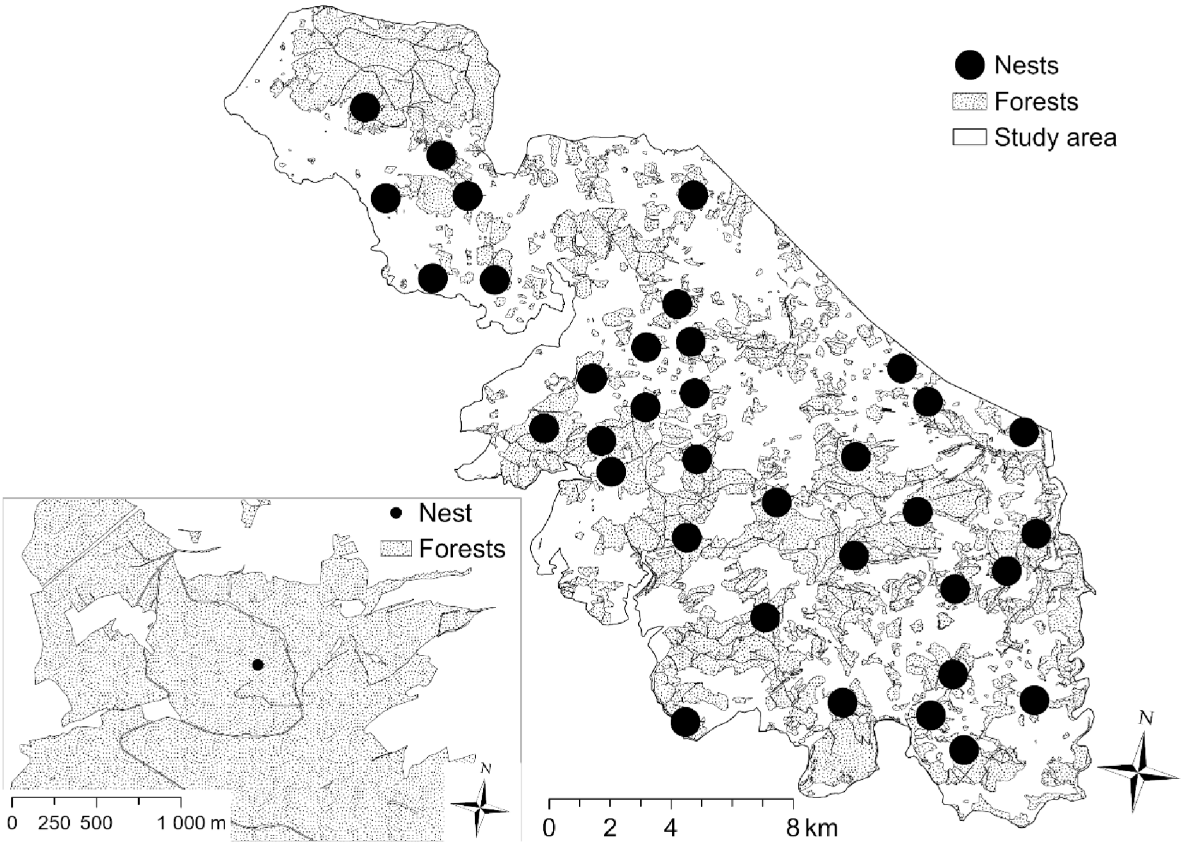

Figure 1. Spatial distribution of the sparrowhawk nests found in the study area from 2020 to 2022 and the position of one nest in the forest. The map was created using ArcGIS pro software (ESRI) with data on forests (FMI 2019).

3.1 Vegetation characteristics around the nests at different spatial scales

No statistically significant differences were found in any of the examined variables, describing landcover, tree species composition and structure of forests, between areas around the nests and random points at the wider home range scale.

However, some differences in examined vegetation characteristics between used and unused areas were found at the territory scale. Using multivariate analysis of variance partitioning for vegetation characteristics recorded as percentages within a 25 m radius around the nests and random points, we found that independent variables (i.e. tree and shrub layers cover, tree species composition, age structure and tree density) were significantly linked with the primary predictors (i.e. nests/random points, PCNM 1, Table 1). Of the total variability (9.5%), 2.9% was explained by primary predictors, 6.3% was explained by space predictors and 0.3% accounted for the shared fraction. After removing spatial effects, the nests and random points were placed along the first ordination axis (Fig. 2). Following independent variables were negatively correlated with both ordination axes: tree layer cover ($r1 = -0.388$, $r2 = -0.146$), age of trees 21 – 30 years ($r1 = -0.319$, $r2 = -0.327$), age of trees 41 – 50 years ($r1 = -0.184$, $r2 = -0.397$) and tree density 100 ($r1 = -0.348$, $r2 = -0.775$). These independent variables were negatively correlated with the first ordination axis and positively correlated with the second ordination axis: age of trees 31 – 40 years ($r1 = -0.356$, $r2 = 0.232$) and tree density 90 ($r1 = -0.025$, $r2 = 0.897$). Only one independent variable was positively correlated with both ordination axes: shrub layer cover ($r1 = 0.431$, $r2 = 0.062$). Independent variables positively correlated with the first ordination axis and negatively correlated with the second ordination axis were: age of trees 81 – 90 years ($r1 = 0.369$, $r2 = -0.018$) and tree density 70 ($r1 = 0.377$, $r2 = -0.049$, Fig. 2). Moreover, percentages of the tree layer cover, trees 21 – 30 years old, trees 31 – 40 years old and a forest stand of tree density 100 (using 100% of the available space) were significantly higher around the nests compared to the random points (Mann-Whitney U test, Table 2, Fig. 3a-d). Forest stands around most of the nests ($n = 32$) consisted mostly of coniferous trees (range = 66.7 – 100%; mean ± SD, 92.7 ± 8.9%, Fig. S3a); around one nest coniferous and broad-leaved species were almost equally represented (50.4% and 49.6% respectively), and around two nests broad-leaved trees were predominant (range = 75.1 – 80.3%; mean ± SD, 77.7 ± 3.7%, Fig. S3b). Nevertheless, tree species composition around the nests was not significantly different compared to the random points at the territory scale.

Table 1. The effect of primary and space predictors on variability of variables recorded as percentages (PCNM 1) and measured in the field (PCNM 2) at the territory scale.

Analysis / predictor	**Contribution (%)**	**pseudo - F**	**p**
PCNM 1			
Primary predictors:			
Nests/random points	34.4	2.3	0.006
Space predictors:			
PCO.2	10.2	2.3	0.004
PCO.4	8.3	1.9	0.026
PCO.3	8.0	1.9	0.022
PCNM 2			
Primary predictors:			
Nests/random points	81.1	26.5	0.002
Space predictors:			
PCO.19	30.8	8.5	0.006
PCO.10	18.3	5.5	0.034

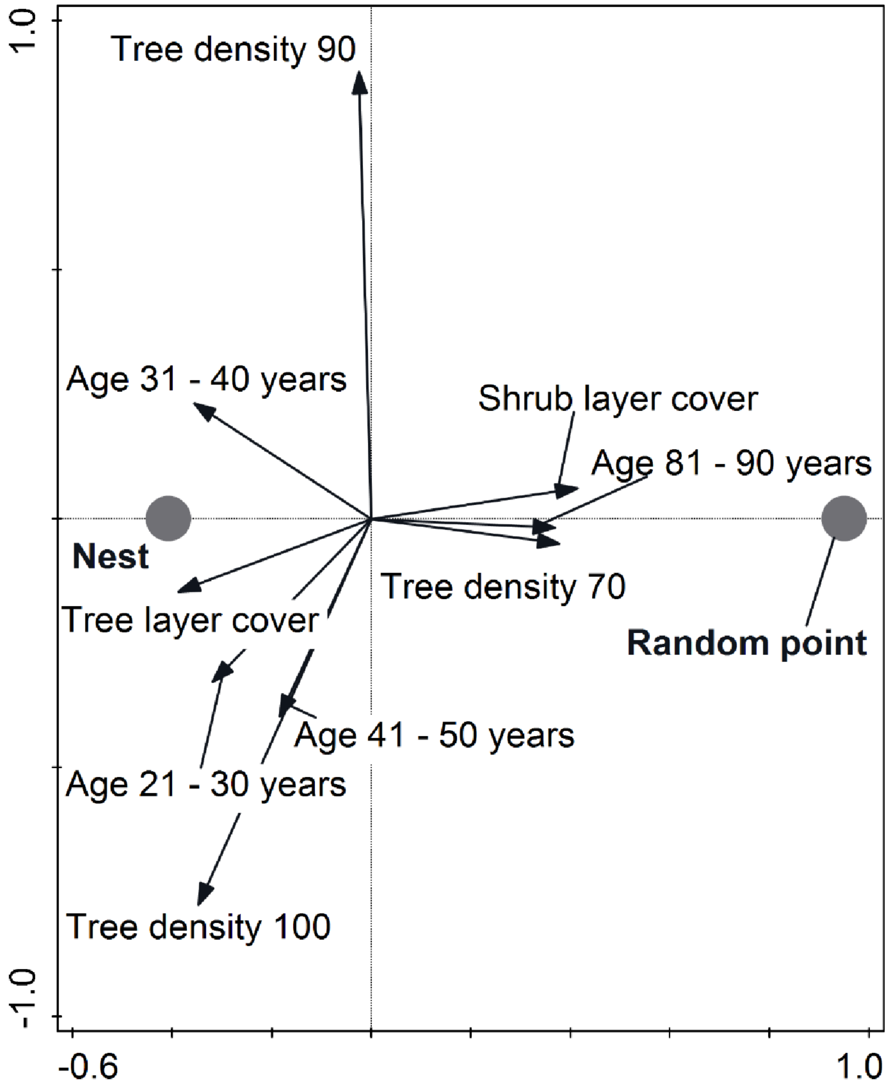

Figure 2. The projection scores for the nests and random points regarding percentages of the area covered by vegetation of different characteristics at the territory scale after removing spatial effects. PCNM analysis, I. and II. ordination axes together explained 22.06% of variability. Only independent variables fitting at least 10% on both ordination axes are displayed. Circles represent nests/random points, arrows represent independent variables (i.e. vegetation characteristics) recorded as percentages of the area around the nest within a 25 m radius, age = age category of trees, tree density = the extent of use of the available space by trees (tree density 70 = 70% of the space was used, tree density 90 = 90% of the space was used, tree density 100 = 100% of the space was used).

Table 2. The results of Mann-Whitney U tests comparing percentages of selected vegetation characteristics based on PCNM analysis and values of measured vegetation characteristics at the territory scale between the nests and random points.

Vegetation characteristic	**Z**	**p**
Tree layer cover (%)	2.540	0.011
Age of trees 21 – 30 years (%)	2.117	0.034
Age of trees 31 – 40 years (%)	2.212	0.027
Tree density 100 (%)	2.413	0.016
Number of trunks	4.594	< 0.001
Mean distance between trunks (m)	−4.912	< 0.001
Mean DBH of trunks (m)	−4.583	< 0.001

Using further multivariate analysis, we found that the independent variables measured in the field (i.e. mean distance between trunks, mean DBH of trunks, slope, number of trunks) at the territory scale were significantly linked with the primary predictors (i.e. nests/random points, PCNM 2, Table 1). Of the total variability (38.2%), 17.6% was explained by primary predictors, 4.0% was explained by space predictors and 16.6% accounted for the shared fraction. After removing spatial effects, the nests and random points were placed along the first ordination axis (Fig. 4). The number of trees was negatively correlated with the first ordination axis and positively correlated with the second ordination axis ($r1 = -0.427$, $r2 = 0.760$), whereas mean distance between trunks and mean DBH of trunks were positively correlated with the first ordination axis and negatively correlated with the second ordination axis ($r1 = 0.628$, $r2 = -0.371$ and $r1 = 0.560$, $r2 = -0.343$ respectively, Fig. 4). Furthermore, the number of trunks (Fig. 3e) was significantly higher around the nests compared to the random points, whilst mean distance between trunks and mean DBH of trunks showed the opposite trends (Mann-Whitney U test, Table 2, Fig. 3f-g).

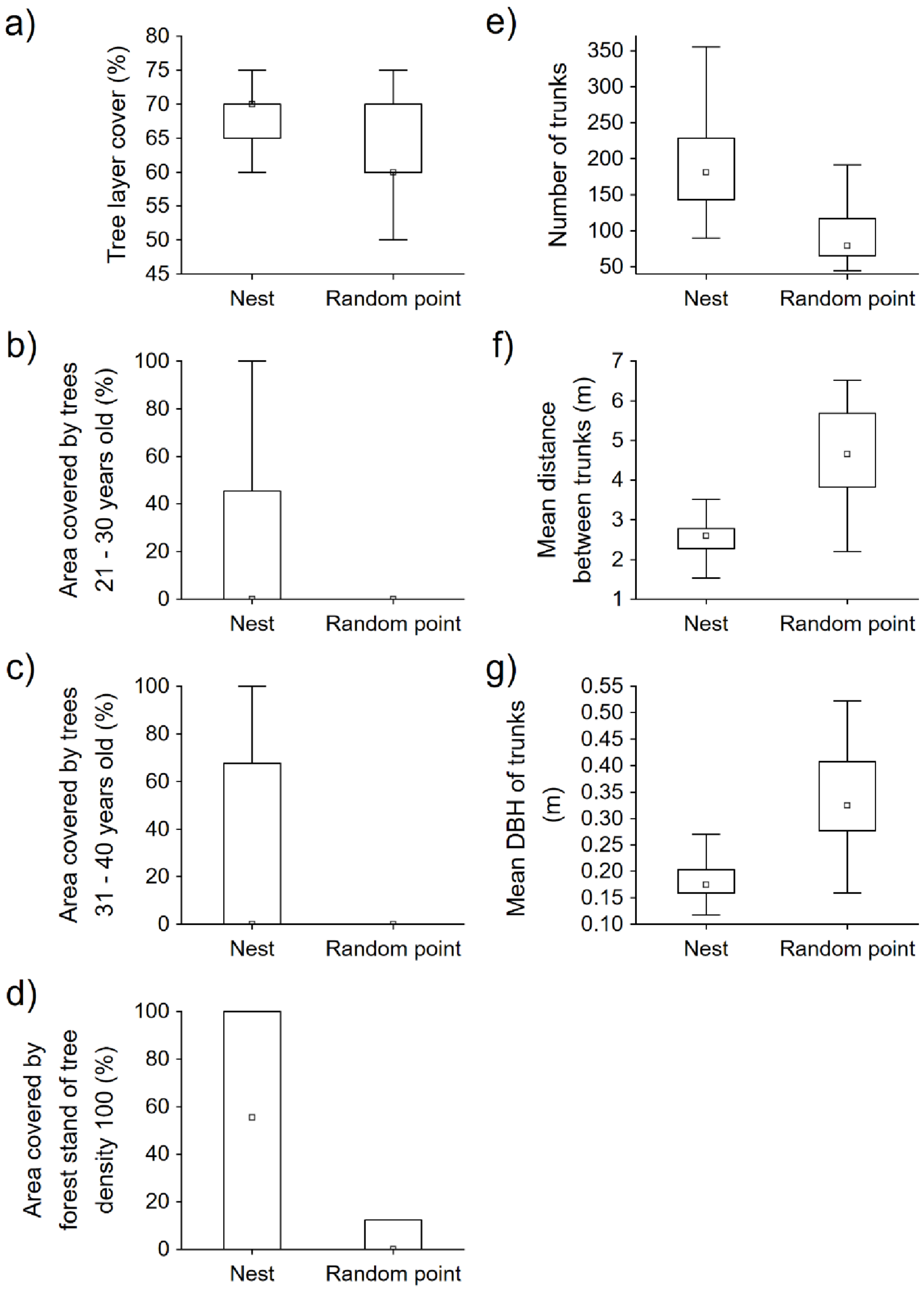

Figure 3. Percentages of the area covered by **(a)** tree layer, **(b)** trees 21 – 30 years old, **(c)** trees 31 – 40 years old, **(d)** forest stand of tree density 100 (using 100% of the space), and **(e)** number of trunks, **(f)** mean distance between trunks, **(g)** mean DBH of trunks at the territory scale within a 25 m radius around the nests and random points. A square mark is median, a box represents 25-75% of data, and the non-outlier range is bounded by whiskers.

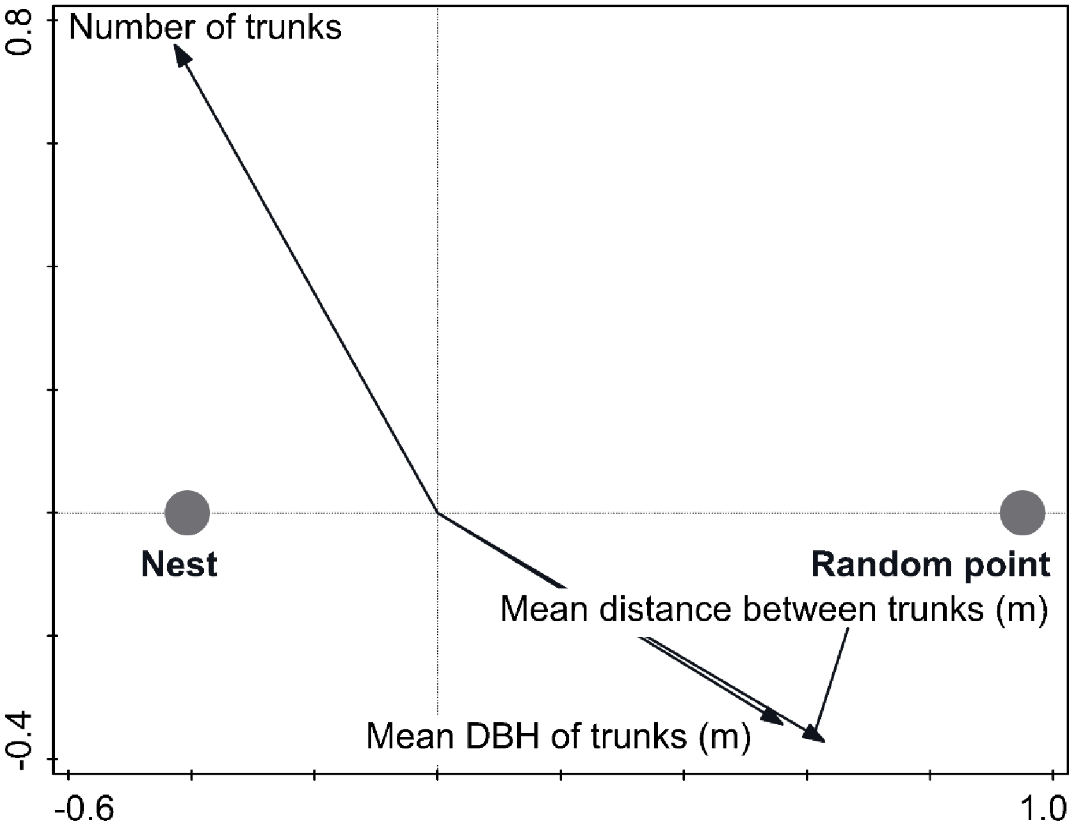

Figure 4. The projection scores for the nests and random points regarding independent variables measured in the field at the territory scale after removing the spatial effects. PCNM analysis, I. and II. ordination axes together explained 99.38% of variability. Only independent variables fitting at least 10% on both ordination axes are displayed. Circles represent nests/random points, arrows represent independent variables (i.e. vegetation characteristics) counted (number of trunks) and measured (mean distance between trunks and mean DBH of trunks) within a 25 m radius around the nests and random points.

3.2 Nest tree characteristics

All the nests were built in coniferous trees, and only three species were used as nest trees. The most frequently used was the Norway spruce (n = 33), followed by the European larch (n = 1) and the Scots pine (n = 1). Nest trees varied in measured characteristics (Table 3). However, a high proportion of the nest trees (n = 30) was within the lowest DBH category 0.1 – 0.3 m (Fig. S4a). Most nest trees (n = 33) had the minimum height of branches up to 1.4 m (Fig. S4b). The majority of nest trees (n = 27) had the minimum height of living branches of 6 – 12 m (Fig. S4c). The range of tree heights was quite wide, but the majority of nest trees (n = 20) were 10 – 16 m tall (Fig. S4d). DBHs of the nest trees were significantly larger than mean DBHs at the territory scale around the nests (Wilcoxon matched pairs test, Z = 2.899, p = 0.004, Fig. 5).

Table 3. The ranges and the means ± SD of nest tree characteristics and positions of the nests in the nest trees.

Nest tree characteristic/position of the nest	**Minimum**	**Maximum**	**Mean ± SD**
DBH (m)	0.11	0.54	0.23 ± 0.09
Minimum height of branches (m)	0.11	2.35	0.74 ± 0.53
Minimum height of living branches (m)	4.00	19.00	9.49 ± 3.29
Tree height (m)	9.00	32.00	16.34 ± 4.93
Nest height (m)	5.00	20.00	10.43 ± 3.19
Position of nest related to tree height (%)	45.50	80.00	63.90 ± 7.30

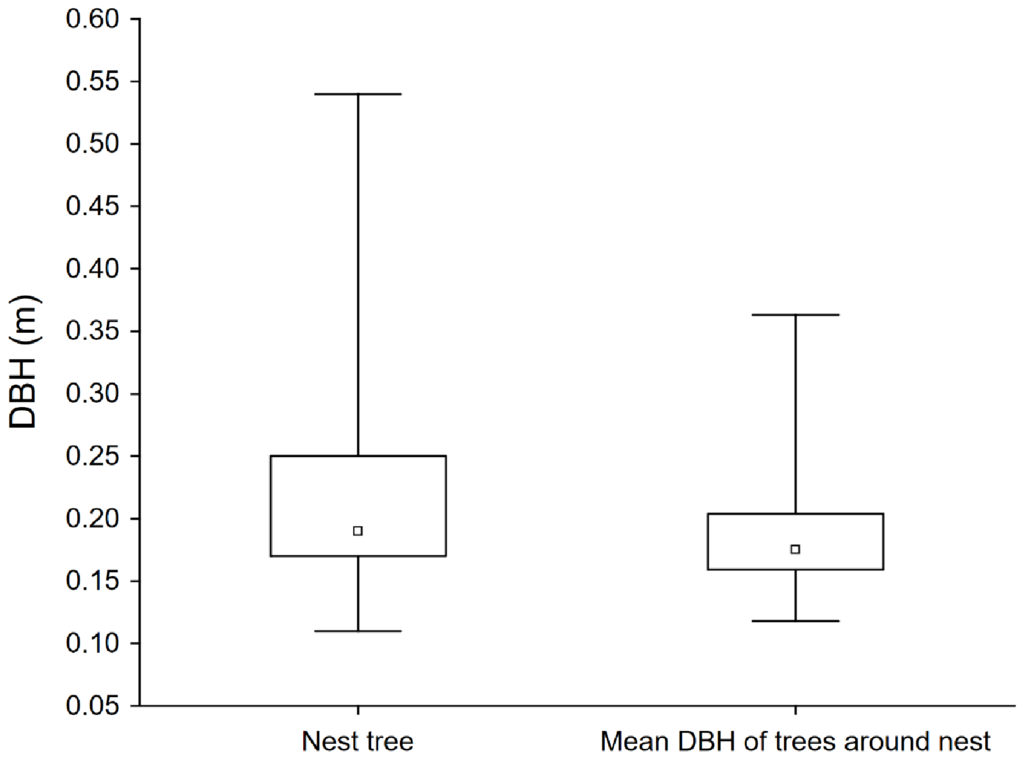

Figure 5. DBH of the nest trees and mean DBH of trees around the nests at the territory scale. A square mark is median, a box represents 25-75% of data, and the non-outlier range is bounded by whiskers.

3.3 Positions of the nests in the nest trees

Positions of the nests in the nest trees also ranged widely (Table 3), but the majority of nests (n = 26) were placed at 8 – 13 m above the ground (Fig. 6a), and most of the nests (n = 30) were built in relative positions related to tree heights of 55 – 75% (Fig. 6b). Furthermore, nest heights were strongly positively correlated with tree heights (r = 0.941, n = 35, $p < 0.001$), and an even stronger positive corelation was between nest heights and minimum heights of living branches (r = 0.956, n = 35, $p < 0.001$). Nearly all the nests were built on first living branches or near them (Fig. 6c), except the two nests which were positioned on dead branches, but directly beneath living ones. All the nests were built close to the tree trunks.

3.4 Food supply

The total number of 7336 records of birds from 60 species potentially belonging to sparrowhawk diet was gathered. The most frequently recorded species were the common chaffinch (*Fringilla coelebs*, 15% of records), coal tit (*Periparus ater*, 9.2%), common chiffchaff (*Phylloscopus collybita*, 7.4%), European robin (*Erithacus rubecula*, 7.2%), common blackbird (*Turdus merula*, 6.9%) and song thrush (*Turdus philomelos*, 6.7%).

Using multivariate analysis of variance partitioning for food supply, we found that food supply species structure was marginally significantly linked with the primary predictors (i.e. nests/random points, PCNM, Table 4). Of the total variability (15.1%), 0.3% was explained by primary predictors, 14.0% was explained by space predictors and 0.8% accounted for the shared fraction. After removing the spatial effects, the nests and random points were placed along the first ordination axis (Fig. 7). Negatively correlated with both ordination axes were the Shannon index of bird diversity (r1 = −0.291, r2 = −0.392) and abundances of following species: the spotted nutcracker (*Nucifraga caryocatactes*, r1 = −0.263, r2 = −0.217), great tit (*Parus major*, r1 = −0.331, r2 = −0.046) and common chiffchaff (r1 = −0.324, r2 = −0.018). Negatively correlated with the first ordination axis and positively correlated with the second ordination axis were abundances of the song thrush (r1 = −0.368, r2 = 0.037), European robin (r1 = −0.372, r2 = 0.029), tree pipit (*Anthus trivialis*, r1 = −0.334, r2 = 0.088), mistle thrush (*Turdus viscivorus*, r1 = −0.273, r2 = 0.081), common firecrest (*Regulus ignicapilla*, r1 = −0.286, r2 = 0.112), wood pigeon (r1 = −0.390, r2 = 0.200), crested tit (*Lophophanes cristatus*, r1 = −0.251, r2 = 0.182), European goldfinch (*Carduelis carduelis*, r1 = −0.250, r2 = 0.228), yellowhammer (*Emberiza citronella*, r1 = −0.236, r2 = 0.342) and hawfinch (*Coccothraustes*

coccothraustes, r1 = −0.172, r2 = 0.274). Positively correlated with both ordination axes were abundances of the common starling (*Sturnus vulgaris*, r1 = 0.053, r2 = 0.839), great spotted woodpecker (*Dendrocopos major*, r1 = 0.063, r2 = 0.424) and common blackbird (r1 = 0.061, r2 = 0.312, Fig. 7). Moreover, abundances of some species, namely the tree pipit, wood pigeon, European robin, great tit, common firecrest and song thrush, and the Shannon index of bird diversity were significantly higher around the nests compared to the random points (Mann-Whitney U test, Table 5, Fig. 8).

Table 4. The effect of primary and space predictors on variability in food supply (PCNM analysis).

Predictors	**Contribution (%)**	**pseudo - F**	**p**
Primary predictors:			
Nests/random points	25.4	1.5	0.103
Space predictors:			
PCO.15	22.4	5.5	0.012
PCO.16	10.6	2.7	0.042
PCO.1	10.6	2.8	0.028

Table 5. The results of Mann-Whitney U tests comparing maximal recorded abundances of selected species and the Shannon index of bird diversity between surroundings of the nests and random points.

Independent variable/species	**Z**	**p**
Anthus trivialis	2.106	0.035
Columba palumbus	2.742	0.006
Erithacus rubecula	2.106	0.035
Parus major	2.117	0.034
Regulus ignicapilla	2.075	0.038
Turdus philomelos	2.064	0.039
Shannon index	2.646	0.008

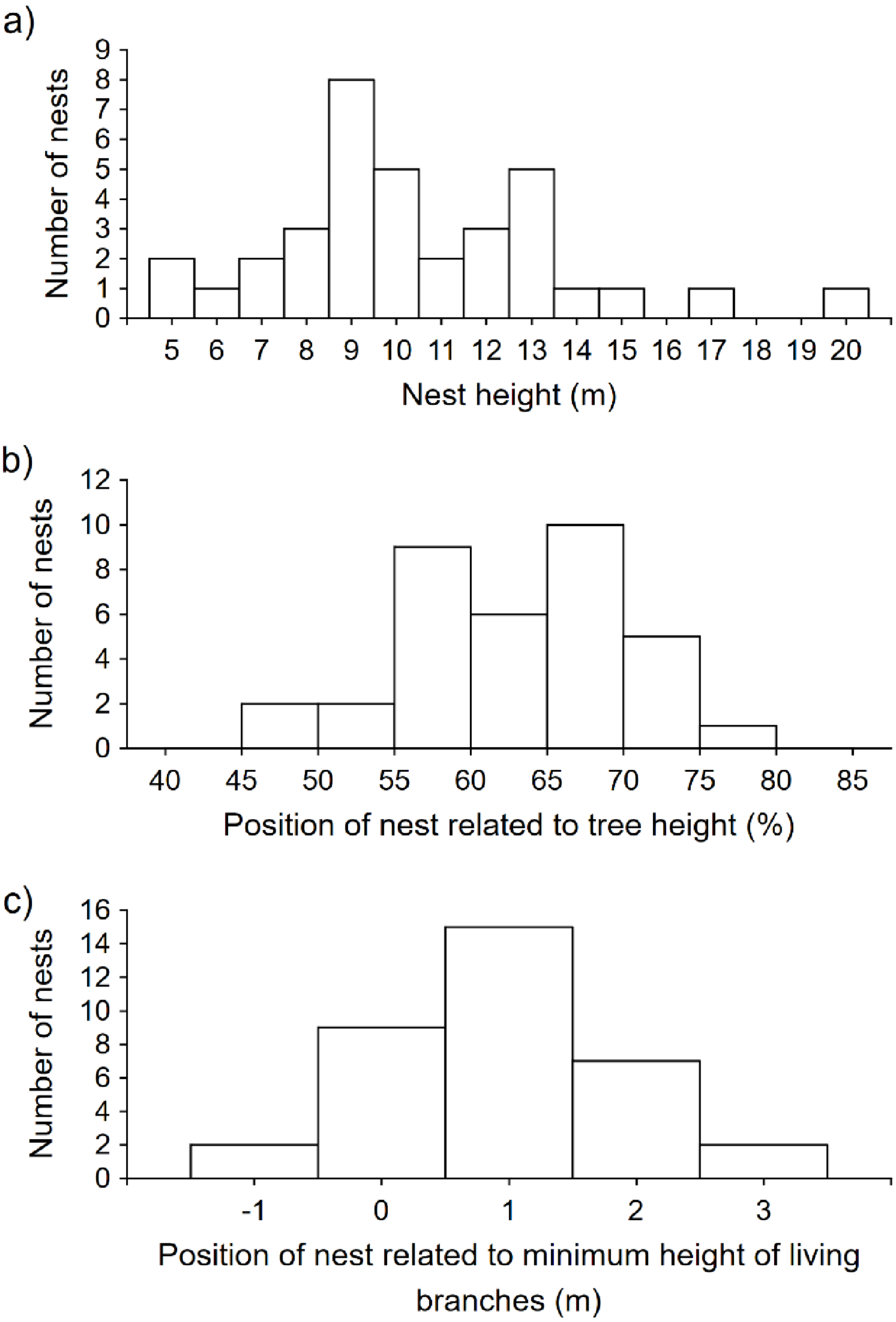

Figure 6. **(a)** The number of nests built at different heights above the ground, **(b)** the number of nests in different categories of relative position related to nest tree height, **(c)** the number of nests in different positions related to minimum height of living branches.

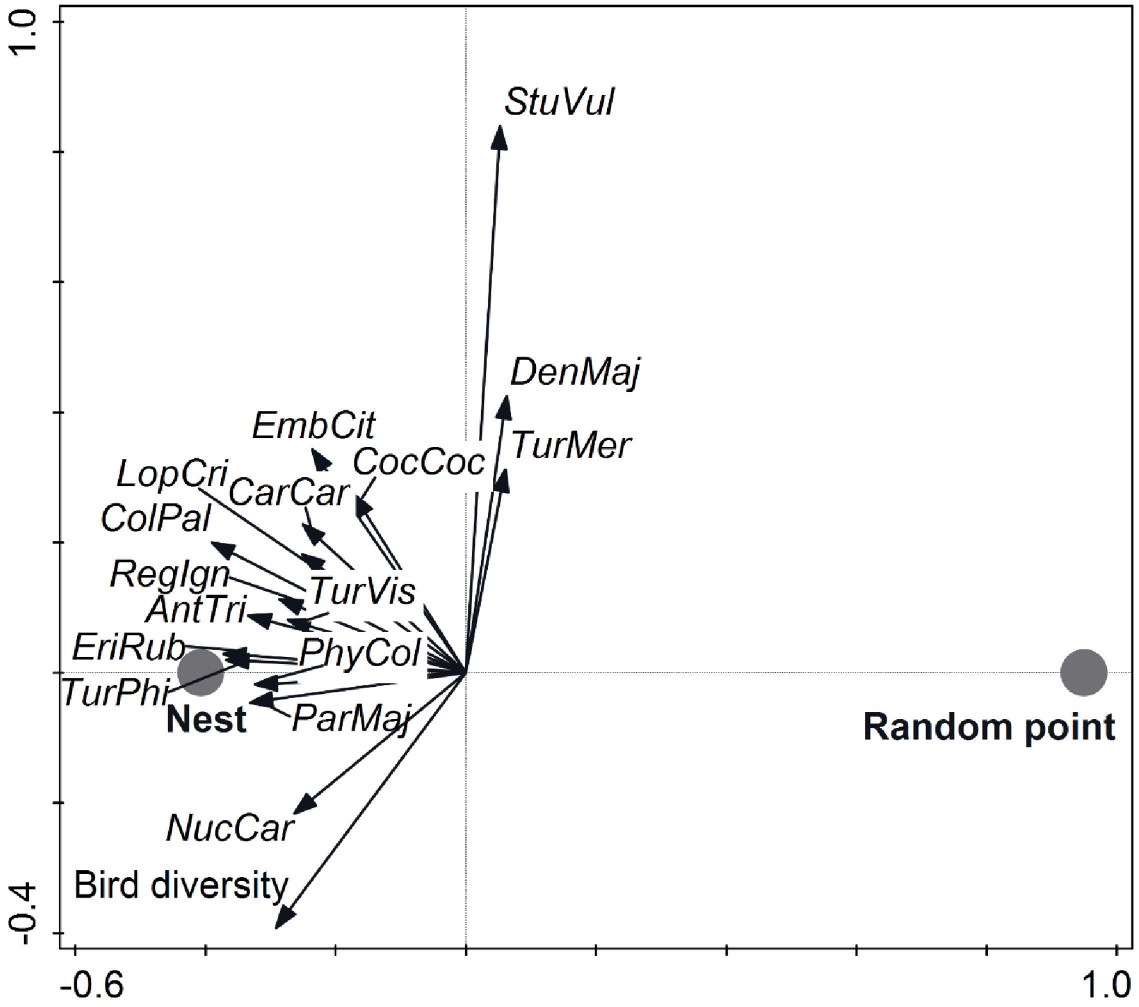

Figure 7. The projection scores for the nests and random points regarding abundances of individual bird species and bird diversity in the surrounding areas after removing the spatial effects. PCNM analysis, I. and II. ordination axes together explained 52.93% of variability. Only species fitting at least 8% on both ordination axes are displayed. Circles represent nests/random points, arrows represent independent variables (i.e. abundances of individual bird species and the Shannon index of bird diversity). Bird diversity represents the Shannon index of diversity. The explanation of species abbreviations: *AntTri* = *Anthus trivialis*, *CarCar* = *Carduelis carduelis*, *CocCoc* = *Coccothraustes coccothraustes*, *ColPal* = *Columba palumbus*, *DenMaj* = *Dendrocopos major*, *EmbCit* = *Emberiza citrinella*, *EriRub* = *Erithacus rubecula*, *LopCri* = *Lophophanes cristatus*, *NucCar* = *Nucifraga caryocatactes*, *ParMaj* = *Parus major*, *PhyCol* = *Phylloscopus collybita*, *RegIgn* = *Regulus ignicapilla*, *StuVul* = *Sturnus vulgaris*, *TurMer* = *Turdus merula*, *TurPhi* = *Turdus philomelos*, *TurVis* = *Turdus viscivorus.*

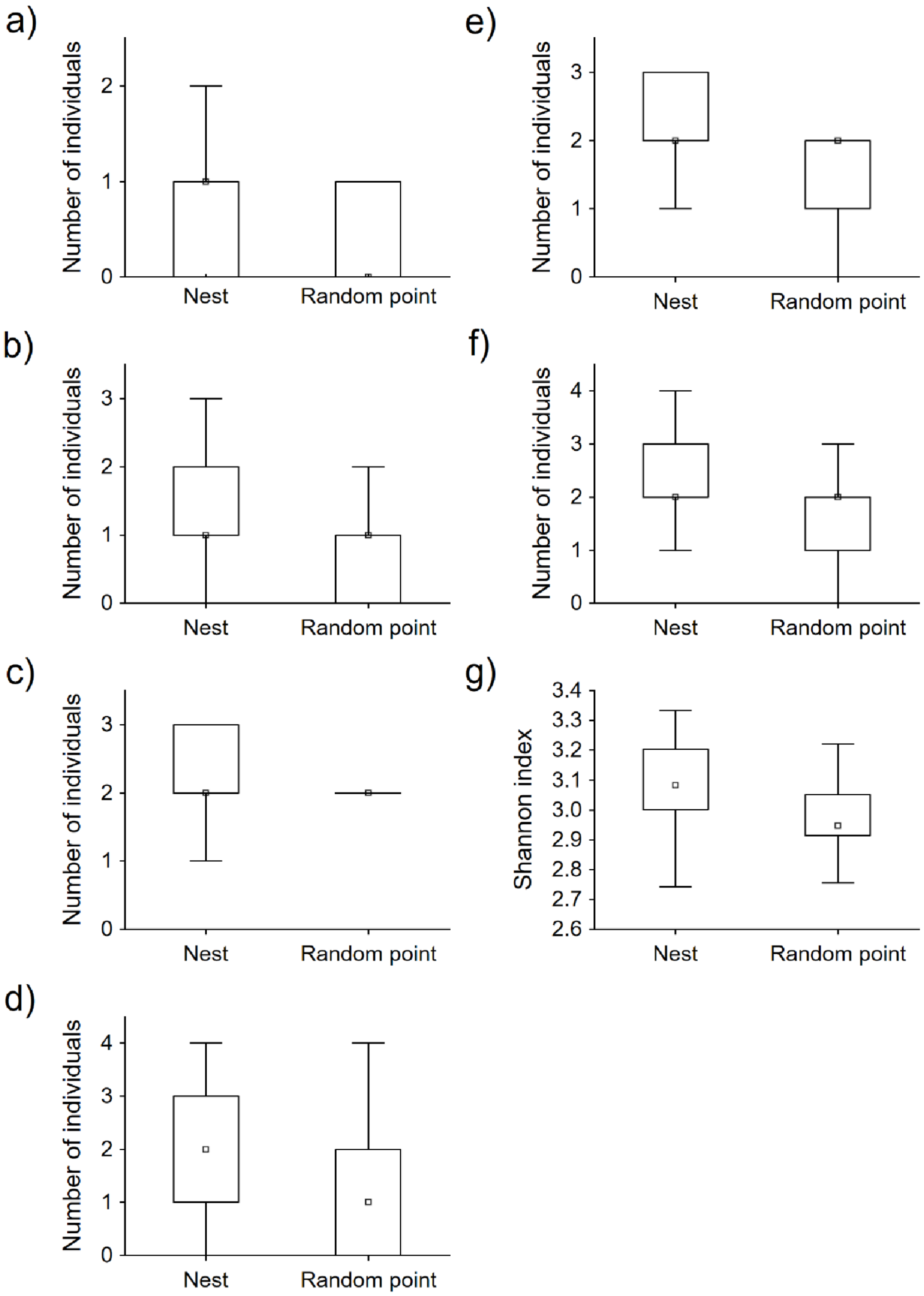

Figure 8. Maximal recorded abundances of **(a)** tree pipit, **(b)** wood pigeon, **(c)** European robin, **(d)** great tit, **(e)** common firecrest and **(f)** song thrush, and **(g)** Shannon index of bird diversity within surroundings of the nests and random points. A square mark is median, a box represents 25-75% of data, and the non-outlier range is bounded by whiskers.

3.5 Foraging preferences

The total number of 324 remains of birds from 31 species likely belonging to sparrowhawk diet was found. The most abundant species were the common blackbird (19.4%), song thrush (15.1%), common chaffinch (11.4%), coal tit (5.9%), common starling (5.9%), Eurasian jay (*Garrulus glandarius*, 4.9%) and great spotted woodpecker (4.9%). Sparrowhawks did not prey upon individual bird species randomly with respect to their abundance in food supply (compositional analysis, $\lambda = 0.001$, $p = 0.002$, Table S2). Some species were more frequently found among prey remains than expected from their occurrence in food supply and vice versa (Table 6, Table S3). The most preferred species were the black redstart (*Phoenicurus ochruros*), white wagtail (*Motacilla alba*), common starling, common blackbird and European greenfinch (*Chloris chloris*). The least preferred species were the Eurasian wren (*Troglodytes troglodytes*), common chiffchaff, Eurasian blackcap (*Sylvia atricapilla*), mistle thrush and European robin.

Table 6. Ranking of individual prey species derived from comparison of their abundance in prey remains and food supply. The higher ranking means that the species was found in prey remains more often than expected based on food supply.

Species	**Ranking**
Phoenicurus ochruros	30
Motacilla alba	29
Sturnus vulgaris	28
Turdus merula	27
Chloris chloris	26
Aegithalos caudatus	25
Motacilla cinerea	24
Prunella modularis	23
Pica pica	22
Turdus pilaris	21
Carduelis carduelis	20
Lanius collurio	19
Turdus philomelos	18
Dendrocopos major	17

Spinus spinus	16
Garrulus glandarius	15
Sylvia communis	14
Fringilla coelebs	13
Cyanistes caeruleus	12
Anthus trivialis	11
Sitta europaea	10
Certhia familiaris	9
Columba palumbus	8
Periparus ater	7
Parus major	6
Pyrrhula pyrrhula	5
Erithacus rubecula	4
Turdus viscivorus	3
Sylvia atricapilla	2
Phylloscopus collybita	1
Troglodytes troglodytes	0

4 Discussion

The sparrowhawk nests were regularly dispersed within the forests of the study area. That is the same pattern reported from other areas (Newton 1986, Solonen 1993, Selås 1997a). The regular distribution of breeding sparrowhawks provides longest possible distances between occupied places within a given area (Marquiss & Newton 1982, Selås & Rafoss 1999) and thus reduces probability of mutual interference (Newton 1986). This result suggests influence of intraspecific competition on breeding habitat selection via its effect on habitat availability (Solonen 1993).

The altitudes of the sparrowhawk nests did not differ from average altitudes in the local topography. This is an unexpected result diverging form reports by Newton (1986) and Selås (1996). However, Selås (1996) reported negative correlation between altitude and tree density complicating interpretation of sparrowhawks' preference for low altitude areas. Therefore, the preference for lower altitudes found by Newton (1986) may be of local importance.

Sparrowhawks bred in forests of various sizes, but they tended to avoid small forest patches. Sparrowhawks generally incline to breed in larger forests (Newton 1986), but in some areas they breed in much smaller forest patches (smaller than 1 ha, Newton 1986, Hervías et al. 2017) compared to our study area. Relatively small forest patches in our area were probably avoided because of sufficient availability of large forests. Selection of large forests for breeding may be beneficial, because they may provide good concealment of nests and breeding activities (i.e. good protection against predators, Newton 1986).

At the home range scale, areas used for breeding by sparrowhawks did not differ in landcover or forest characteristics from randomly selected unused areas. In contrast, Selås & Rafoss (1999) found that sparrowhawks preferred increased proportions of medium-aged forests within their home ranges. The similarity of used and unused areas at the home range scale may have been caused by somewhat regular distribution of forests within our study area and their overall homogeneity, possibly providing similar proportions of individual types of forests in any selected area.

At the territory scale, breeding sparrowhawks were clearly linked to denser forest stands characterized by higher tree layer cover, higher proportion of trees 21 – 40 years old and forest stands of maximum tree density, higher number of trees, shorter mean distance between trunks and smaller DBH of trunks compared to unused forest stands. The combined influence of these characteristics probably resulted in optimal forest structure (i.e. mainly suitable density and age of trees) required by breeding sparrowhawks. Similar selectivity of breeding sparrowhawks for forests of particular structure was also found in other areas (Newton 1986, Fasola & Zanghellini 1993, Selås 1996, Selås 1997b, Abe et al. 2007, Diviš 2018). Optimal forest structure is likely required, because it may provide a crucial combination of protection against predators together with sufficient space for sparrowhawks' movements (Newton 1986, Selås 1996). However, sparrowhawks may sometimes nest in more open forest stands when the predation pressure is diminished (Newton 1986).

The majority of forest stands used by breeding sparrowhawks consisted mostly of coniferous trees at the territory scale. Nevertheless, tree species composition did not differ from unused areas. In general, sparrowhawks tend to select their breeding territories in coniferous forest stands, probably because they provide better protection against predators than mixed and broad-leaved stands (Newton 1986, Abe et al. 2007, Diviš 2018). However, tree species composition in our study area did not seem to affect breeding habitat selection at the territory scale, similarly to Selås (1996), probably because of the overall prevalence of coniferous trees within the study area.

All the sparrowhawk nests were built in coniferous trees. This finding may have been attributed to the prevalence of coniferous trees within occupied territories. However, even when breeding in forest stands consisting mainly of broad-leaved trees, the sparrowhawks selected conifers for building their nests. Also other authors reported that sparrowhawks usually incline to build their nests in coniferous trees if they are available (Newton 1986, Fasola & Zanghellini 1993, Abe et al. 2007, Diviš 2018). Coniferous trees may be preferable, because they may provide sufficient concealment and protection against predators (Newton 1986, Abe et al. 2007). Moreover, coniferous trees may provide more suitable platforms for building nests, because of the whorl arrangement and almost horizontal growth of their branches likely forming a better support for nests compared to broad-leaved trees whose branches usually grow in alternating order and upwards. Furthermore, sparrowhawks selected trees larger in diameter than the mean within their territories for building nests, presumably because they provided a better support for the nests. Similar selection of larger trees within sparrowhawk territories was also found by Fasola & Zanghellini (1993) and Abe et al. (2007).

The sparrowhawk nests were built close to the first living branches and the trunks of the nest trees. Sparrowhawk nests positioned similarly in lower parts of green crowns and close to trunks of coniferous trees were also found in managed forests by Newton (1986). Therefore, forest management likely affects indirectly positions of sparrowhawk nests in nest trees. The preferred position may provide the best possible concealment of a nest against ground and aerial predators along with stability of a nest on several branches growing close together from a trunk (Newton 1986).

Breeding sparrowhawks marginally significantly followed the structure of food supply with abundances of some bird species and diversity of birds higher in surroundings of their nests compared to random areas. Interestingly, some bird species, namely the wood pigeon, European robin, great tit and song thrush, occurring in higher abundances around sparrowhawk nests were reported to form an important part of the diet of breeding sparrowhawks (Newton & Marquiss 1982, Newton 1986, Selås 1993, Solonen 1997, Bujoczek & Ciach 2009). This result suggests an effect of food supply on sparrowhawks' breeding habitat selection, possibly because it may be beneficial to breed within areas with higher food supply to increase probability of obtaining food while reducing effort and time spent searching for prey.

Sparrowhawks did not prey upon individual bird species proportionally to their abundance in the food supply. According to Newton (1986), Selås (1993), Götmark & Post (1996) and Rytkönen et al. (1998) some bird species may be preferred because they may be more beneficial to hunt. Larger birds may provide more food for the effort and may be less manoeuvrable and easier to catch, although too large birds may increase a risk of injury. Some birds may be easy to find and catch because of their conspicuousness (e.g. birds foraging in open areas, exhibiting striking behaviour or plumage colouration), whilst others may be neglected because of their elusiveness (e.g. birds living in undergrowth, having cryptic plumage colouration). In our study area, the five most preferred species were the black redstart, white wagtail, common starling, common blackbird and European greenfinch, whilst the five least preferred species were the Eurasian wren, common chiffchaff, Eurasian blackcap, mistle thrush and European robin. Black redstarts and white wagtails may be vulnerable because they usually visit open areas to forage. Redstarts, although different species (*Phoenicurus phoenicurus*), were reported by Tinbergen (1946) to be preferred prey species, whereas Selås (1993) and Rytkönen et al. (1998) found that they were almost neglected. Selås (1993) reported white wagtails to be preferred prey similarly to our findings, but Rytkönen et al. (1998) found almost proportional use of this species to its occurrence in the environment. Common starlings and common blackbirds are rather larger songbirds with conspicuously colourful plumage (especially males in blackbirds), and they also tend to forage in open areas potentially drawing attention of hunting sparrowhawks. They were also found vulnerable to sparrowhawk predation by Selås (1993), whereas Tinbergen (1946) reported somewhat low vulnerability of common blackbirds. European greenfinches may be preferred because of their size as documented by other authors (Götmark & Post 1996, Solonen 1997). Eurasian wrens, common chiffchaffs, Eurasian blackcaps and European robins generally live inconspicuously in undergrowth, shrubs or tree crowns hidden in foliage. Therefore, they may be difficult to notice, although Selås (1993) found that Eurasian blackcaps and European robins were preferred sparrowhawks' prey. Mistle thrushes are the largest thrushes within our study area and thus possibly too large and difficult to kill especially for males (Newton & Marquiss 1982). Nonetheless, much larger wood pigeons were somewhat more preferred prey. However, our result should be considered cautiously because of possible underrepresentation of some species in the food supply inhabiting mainly areas where counting was not conducted (e.g. the black redstart, white wagtail and European greenfinch usually occurring in human settlements within our study area). Although this result also implies that sparrowhawks may hunt further away from their nests likely visiting human settlements. Another potential source of bias may have likely been the limited information on sparrowhawk diet gathered during this study.

In conclusion, sparrowhawks preferred to breed as far away from each other as possible. They also preferred larger forests and forest stands of specific structure for breeding. They built their nests only in coniferous trees in the lower parts of their green crowns and close to the trunks. They seemed to prefer areas with increased diversity of birds and with increased abundances of some bird species, and some bird species were hunted more frequently than other species. To conclude, the important factors affecting sparrowhawks' breeding habitat selection appeared to be intraspecific competition, sizes of available forests, structure of forest stands, availability of coniferous trees for building nests and heights of their first living branches. Structure of food supply close to the nests seemed to be somewhat important, but the sparrowhawks also hunted within wider areas.

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6 Supplementary material

Table S1. The bird species recorded during the survey of food supply.

Species	Species
Acrocephalus palustris	*Muscicapa striata*
Acrocephalus scirpaceus	*Nucifraga caryocatactes*
Aegithalos caudatus	*Parus major*
Alauda arvensis	*Periparus ater*
Anthus pratensis	*Phoenicurus ochruros*
Anthus trivialis	*Phylloscopus collybita*
Carduelis carduelis	*Phylloscopus sibilatrix*
Certhia familiaris	*Phylloscopus trochilus*
Coccothraustes coccothraustes	*Pica pica*
Columba oenas	*Picus viridis*
Columba palumbus	*Poecile montanus*
Coturnix coturnix	*Poecile palustris*
Crex crex	*Prunella modularis*
Cuculus canorus	*Pyrrhula pyrrhula*
Cyanistes caeruleus	*Regulus ignicapilla*
Delichon urbica	*Regulus regulus*
Dendrocopos major	*Saxicola rubetra*
Dryocopus martius	*Sitta europaea*
Emberiza citrinella	*Spinus spinus*
Erithacus rubecula	*Streptopelia turtur*
Fringilla coelebs	*Sturnus vulgaris*
Garrulus glandarius	*Sylvia atricapilla*
Hirundo rustica	*Sylvia borin*
Chloris chloris	*Sylvia communis*
Lanius collurio	*Sylvia curruca*
Locustella naevia	*Troglodytes troglodytes*
Lophophanes cristatus	*Turdus philomelos*
Loxia curvirostra	*Turdus merula*
Motacilla alba	*Turdus pilaris*
Motacilla cinerea	*Turdus viscivorus*

Table S2. The ranking matrix from compositional analysis of sparrowhawk foraging preferences. The signs signify whether a species in a row was preferred as prey (+) to corresponding species in columns or not (-). Triple signs (+++ or ---) indicate a significant difference ($p < 0.05$), whereas single signs (+ or -) indicate a non-significant difference.

	Tur.mer	*Tur.phi*	*Tur.vis*	*Tur.pil*	*Par.maj*	*Cya.cae*	*Per.ate*	*Mot.alb*	*Fri.coe*	*Car.car*	*Spi.spi*	*Eri.rub*	*Tro.tro*	*Syl.atr*	*Syl.com*	*Ant.tri*
Tur.mer	0															
Tur.phi	---	0														
Tur.vis	---	---	0													
Tur.pil	-	+	+++	0												
Par.maj	---	---	+	---	0											
Cya.cae	---	-	+++	---	+	0										
Per.ate	---	---	+	---	+	-	0									
Mot.alb	+	+++	+++	+	+++	+++	+++	0								
Fri.coe	---	-	+++	---	+++	+	+	---	0							
Car.car	-	+	+++	-	+++	+++	+++	-	+++	0						
Spi.spi	---	-	+++	---	+++	+	+++	---	+	-	0					
Eri.rub	---	---	+	---	-	---	-	---	---	---	---	0				
Tro.tro	---	---	-	---	---	---	---	---	---	---	---	-	0			
Syl.atr	---	---	-	---	-	---	-	---	---	---	---	-	+	0		
Syl.com	---	-	+++	---	+++	+	+++	---	+	-	-	+++	+++	+++	0	
Ant.tri	---	---	+	---	+	-	+	---	-	---	-	+++	+++	+++	-	0
Pyr.pyr	---	---	+	---	-	---	-	---	---	---	---	+	+++	+	---	-
Den.maj	---	-	+++	-	+++	+	+++	---	+	-	+	+++	+++	+++	+	+
Gar.gla	---	-	+++	---	+++	+	+++	---	+	-	-	+++	+++	+++	+	+
Pic.pic	-	+++	+++	+	+++	+++	+++	-	+++	+	+++	+++	+++	+++	+++	+++
Phy.col	---	---	-	---	-	---	---	---	---	---	---	-	+	-	---	---
Stu.vul	+	+	+++	+	+++	+++	+++	-	+++	+	+	+++	+++	+++	+++	+++
Chlo.chlo	-	+++	+++	+	+++	+++	+++	-	+++	+	+++	+++	+++	+++	+++	+++
Sit.eur	---	---	+	---	+	-	+	---	-	---	-	+	+++	+++	-	-
Col.pal	---	---	+	---	+	-	+	---	-	---	---	+	+++	+	---	-
Cer.fam	---	---	+	---	+	-	+	---	-	---	---	+	+++	+	-	-
Pru.mod	-	+++	+++	+	+++	+++	+++	-	+++	+	+++	+++	+++	+++	+++	+++
Lan.col	-	+	+++	-	+++	+++	+++	-	+++	-	+	+++	+++	+++	+++	+++
Aeg.cau	-	+++	+++	+	+++	+++	+++	-	+++	+	+++	+++	+++	+++	+++	+++
Mot.cin	-	+++	+++	+	+++	+++	+++	-	+++	+	+++	+++	+++	+++	+++	+++
Pho.ochr	+	+++	+++	+	+++	+++	+++	+	+++	+++	+++	+++	+++	+++	+++	+++

Table S2. Continued

	Pyr.pyr	*Den.maj*	*Gar.gla*	*Pic.pic*	*Phy.col*	*Stu.vul*	*Chlo.chlo*	*Sit.eur*	*Col.pal*	*Cer.fam*	*Pru.mod*	*Lan.col*	*Aeg.cau*	*Mot.cin*	*Pho.ochr*
Pyr.pyr	0														
Den.maj	+++	0													
Gar.gla	+++	-	0												
Pic.pic	+++	+++	+++	0											
Phy.col	-	---	---	---	0										
Stu.vul	+++	+++	+++	+	+++	0									
Chlo.chlo	+++	+++	+++	+	+++	-	0								
Sit.eur	+	---	-	---	+++	---	---	0							
Col.pal	+	---	-	---	+++	---	---	-	0						
Cer.fam	+	---	---	---	+	---	---	-	+	0					
Pru.mod	+++	+++	+++	+	+++	-	-	+++	+++	+++	0				
Lan.col	+++	+	+	-	+++	-	-	+++	+++	+++	-	0			
Aeg.cau	+++	+++	+++	+	+++	-	-	+++	+++	+++	+	+	0		
Mot.cin	+++	+++	+++	+	+++	-	-	+++	+++	+++	+	+	-	0	
Pho.ochr	+++	+++	+++	+	+++	+	+	+++	+++	+++	+	+	+	+	0

The explanation of species abbreviations used in the Table S2: *Aeg.cau* = *Aegithalos caudatus*, *Ant.tri* = *Anthus trivialis*, *Car.car* = *Carduelis carduelis*, *Cer.fam* = *Certhia familiaris*, *Col.pal* = *Columba palumbus*, *Cya.cae* = *Cyanistes caeruleus*, *Den.maj* = *Dendrocopos major*, *Eri.rub* = *Erithacus rubecula*, *Fri.coe* = *Fringilla coelebs*, *Gar.gla* = *Garrulus glandarius*, *Chlo.chlo* = *Chloris chloris*, *Lan.col* = *Lanius collurio*, *Mot.alb* = *Motacilla alba*, *Mot.cin* = *Motacilla cinerea*, *Par.maj* = *Parus major*, *Per.ate* = *Periparus ater*, *Pho.ochr* = *Phoenicurus ochruros, Phy.col* = *Phylloscopus collybita*, *Pic.pic* = *Pica pica*, *Pru.mod* = *Prunella modularis*, *Pyr.pyr* = *Pyrrhula pyrrhula*, *Sit.eur* = *Sitta europaea*, *Spi.spi* = *Spinus spinus*, *Stu.vul* = *Sturnus vulgaris*, *Syl.atr* = *Sylvia atricapilla*, *Syl.com* = *Sylvia communis*, *Tro.tro* = *Troglodytes troglodytes*, *Tur.mer* = *Turdus merula*, *Tur.phi* = *Turdus philomelos*, *Tur.pil* = *Turdus pilaris*, *Tur.vis* = *Turdus viscivorus.*

Table S3. The mean number of individuals ± SD of each bird species recorded in food supply and among prey remains per breeding locality. Species are ordered from the highest to the lowest occurrence among prey remains.

Species	**Food supply**	**Prey remains**
Turdus merula	2.29 ± 1.02	1.80 ± 1.68
Turdus philomelos	2.23 ± 0.65	1.40 ± 1.85
Fringilla coelebs	3.63 ± 0.69	1.06 ± 1.21
Sturnus vulgaris	1.34 ± 3.16	0.54 ± 0.92
Periparus ater	3.34 ± 1.21	0.54 ± 0.82
Erithacus rubecula	2.31 ± 0.53	0.34 ± 0.91
Garrulus glandarius	1.06 ± 0.76	0.46 ± 0.78
Dendrocopos major	1.00 ± 0.64	0.46 ± 0.66
Parus major	2.14 ± 1.26	0.31 ± 0.58
Carduelis carduelis	0.83 ± 1.34	0.26 ± 0.56
Cyanistes caeruleus	1.17 ± 1.32	0.17 ± 0.57
Columba palumbus	1.63 ± 1.03	0.26 ± 0.44
Lanius collurio	0.43 ± 0.88	0.14 ± 0.55
Sylvia atricapilla	2.17 ± 0.66	0.20 ± 0.47
Phoenicurus ochruros	0.03 ± 0.17	0.14 ± 0.43
Turdus viscivorus	1.91 ± 1.07	0.14 ± 0.36
Phylloscopus collybita	2.09 ± 0.45	0.14 ± 0.36
Prunella modularis	0.20 ± 0.41	0.14 ± 0.36
Motacilla alba	0.09 ± 0.28	0.11 ± 0.32
Turdus pilaris	0.31 ± 0.76	0.09 ± 0.28
Sitta europaea	1.23 ± 1.03	0.09 ± 0.28
Spinus spinus	0.97 ± 1.29	0.06 ± 0.24
Troglodytes troglodytes	1.51 ± 0.51	0.06 ± 0.24
Sylvia communis	0.66 ± 0.87	0.06 ± 0.24
Anthus trivialis	0.86 ± 0.77	0.06 ± 0.24
Pica pica	0.14 ± 0.49	0.06 ± 0.24
Certhia familiaris	1.17 ± 0.82	0.06 ± 0.24
Pyrrhula pyrrhula	1.34 ± 0.94	0.03 ± 0.17
Chloris chloris	0.06 ± 0.34	0.03 ± 0.17
Aegithalos caudatus	0.03 ± 0.17	0.03 ± 0.17
Motacilla cinerea	0.03 ± 0.17	0.03 ± 0.17

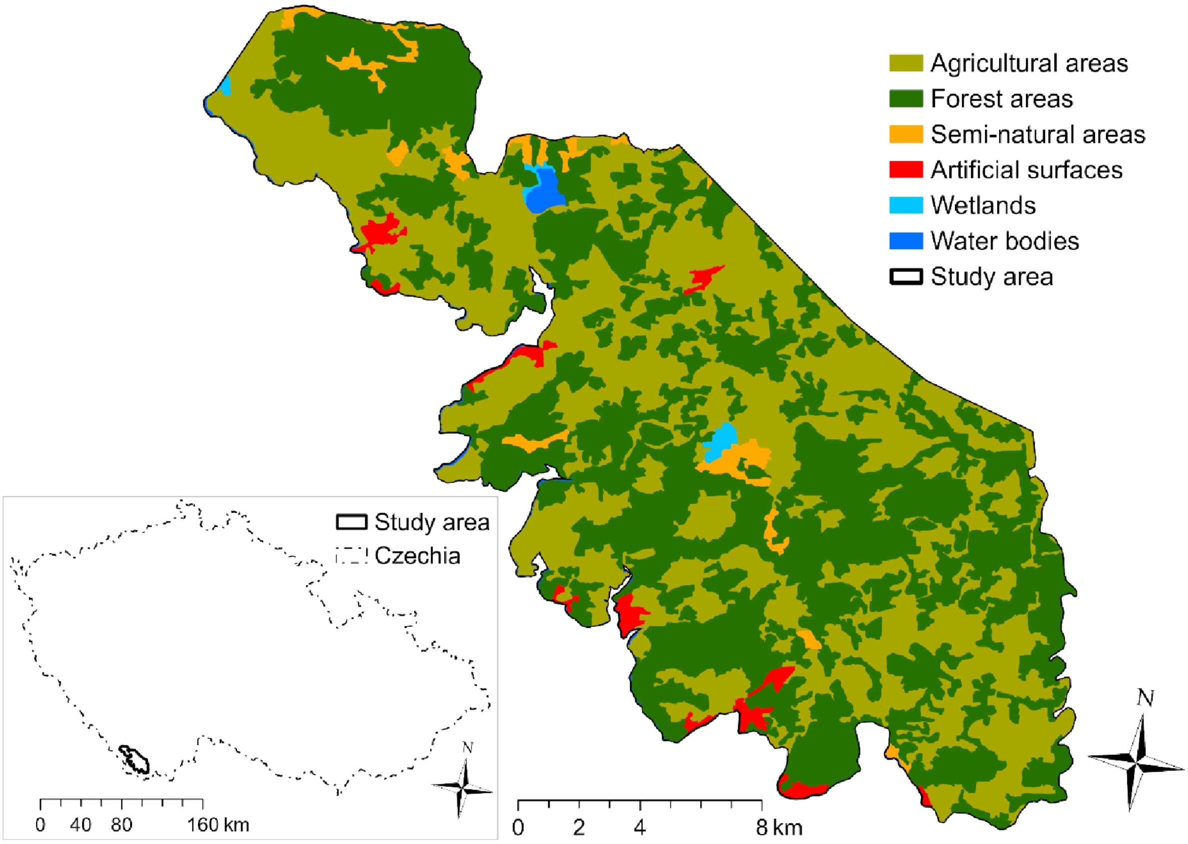

Figure S1. The location and the landcover of the study area. The map was created using ArcGIS pro software (ESRI) with data on administrative boundary of Czechia (ArcČR © ČÚZK, ČSÚ, ARCDATA PRAHA 2022) and data on the landcover (CORINE Land Cover 2018).

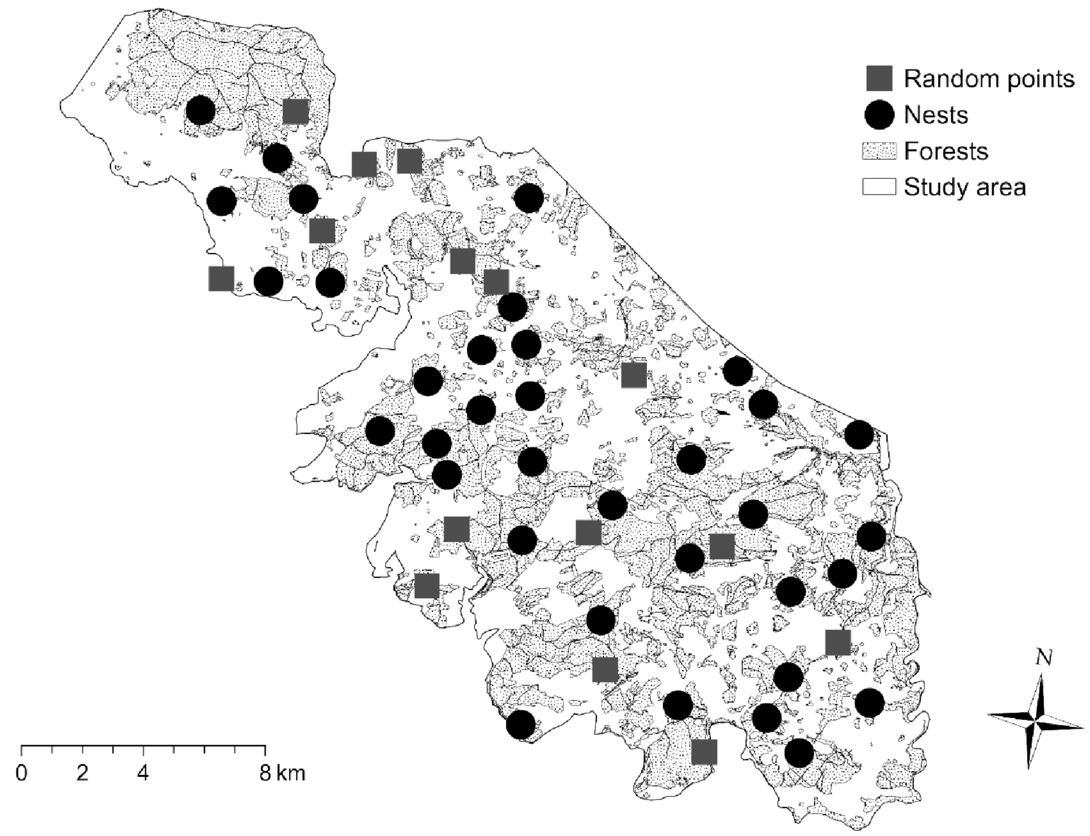

Figure S2. Spatial distribution of the random points created in forests at the minimum distance of 1 km from the nearest known sparrowhawk nest and from each other in the study area. The map was created using ArcGIS pro software (ESRI) with data on forests (FMI 2019).

Figure S3. The forest stands around sparrowhawk nests with **(a)** prevalence of coniferous trees and **(b)** prevalence of broad-leaved trees. The forest structure remains comparable regardless of the tree species composition. Red arrows indicate positions of the sparrowhawk nests.

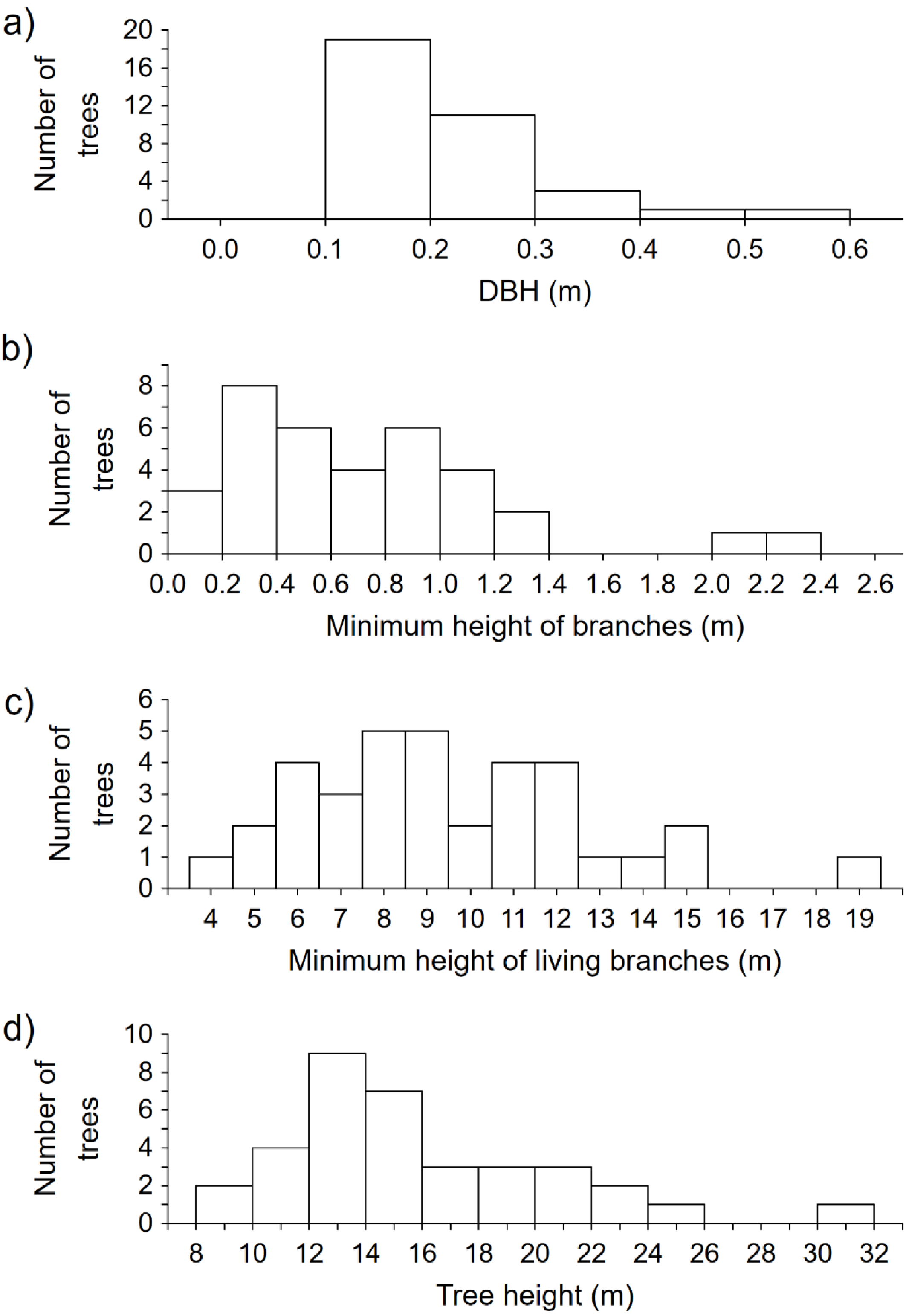

Figure S4. **(a)** The number of nest trees in different categories of DBH, **(b)** the number of nest trees in different categories of minimum height of branches, **(c)** the number of nest trees in different categories of minimum height of living branches, **(d)** the number of nest trees in different categories of tree height.