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Diet specialization of the Eurasian Sparrowhawk *Accipiter nisus* in Pošumaví

Master's thesis

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České Budějovice 2024

Dvořák, T., 2024: Diet specialization of the Eurasian Sparrowhawk *Accipiter nisus* in Pošumaví. Mgr. Thesis, in English. – 51 p., Faculty of Science, University of South Bohemia, České Budějovice, Czech Republic.

Annotation

Diet composition of the Eurasian Sparrowhawk *Accipiter nisus* in relation to food supply, land cover, and prey species characteristics in Pošumaví was studied. The effect of land cover on the structure of food supply and Eurasian Sparrowhawk diet composition was tested. Eurasian Sparrowhawks' hunting preferences were assessed. Eurasian Sparrowhawks' prey selection in relation to several prey species characteristics was examined. The effect of geographical distance on the inter-pair similarity of Eurasian Sparrowhawk diet was tested.

I declare that I am the author of this qualification thesis and that in writing it I have used the sources and literature displayed in the list of used sources only.

České Budějovice, 30 November 2024.

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Bc. Tomáš Dvořák

Acknowledgments

I would like to thank my supervisor doc. Mgr. Jan Riegert, Ph.D. for providing his guidance, support, and useful advice during my work on this thesis. I am also grateful to my family for their indispensable support.

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1 Introduction

Many bird species are predators feeding on animals from lower trophic levels. However, only a limited number of bird lineages have adapted for hunting relatively large prey (mainly vertebrates), sometimes even larger than themselves. Such birds can be referred to as birds of prey or raptors. However, raptors are difficult to define since various bird taxa (e.g. skuas Stercorariidae, shrikes Laniidae) have been regarded as raptors due to their similar morphological adaptations and raptorial lifestyle. Therefore, a definition of raptors based on phylogeny, morphology and ecology has been recently proposed, and it includes the orders Accipitriformes, Cathartiformes, Strigiformes, Cariamiformes, and Falconiformes (McClure et al. 2019). Therefore, the term raptors refers to the members of these orders throughout this study.

1.1 Raptors' general adaptations related to their diet

Raptors have evolved many adaptations helping them with the procurement of food including exceptional vision, strong feet with large talons, hooked beaks, and also diverse flight capabilities (Savile 1957, del Hoyo et al. 1994, Corvidae et al. 2006, Jones et al. 2007, Tsang et al. 2019). However, different modifications of adaptations can be found within different groups of raptors mainly depending on the way of food procurement. Generally, majority of raptors may be classified as: predators mostly hunting live prey (e.g. eagles, hawks, falcons), opportunists capable of hunting usually small prey but substantially relying on scavenging (e.g. caracaras, kites *Milvus* spp.), or scavengers specialized in finding and eating large carcasses (e.g. New World and Old World vultures, Wilman et al. 2014). Raptors' exceptional vision includes high accommodative power, high visual acuity (some species showed the highest visual acuity recorded among all animals, Potier et al. 2016), relatively high temporal resolution of vision, high chromatic spatial resolution, and high light sensitivity. Their visual capabilities are generally important for all raptors since they enable them to detect prey or carrion even from long distances, at high speed or during poor light conditions in owls (Jones et al. 2007, Mitkus et al. 2017, Potier 2020). Predatory raptors usually have wider binocular visual field enabling them to focus on prey compared to scavengers with wider monocular visual field important for detecting conspecifics and predators (Potier 2020). Predatory raptors usually have strong feet with relatively large and strong talons enabling them to catch, hold,

and kill their prey (Goslow 1972, Fowler et al. 2009). Conversely, scavengers usually have relatively short first toe and relatively straight talons facilitating walking on the ground (Ferguson-Lees & Christie 2001). Raptors' sharp, hooked beaks facilitate tearing small swallowable pieces of meat from large animals that cannot be eaten as a whole. Some scavengers have particularly large and strong beaks capable of tearing skin of large mammals (Ferguson-Lees & Christie 2001, Bright et al. 2016, Linde-Medina et al. 2021). Moreover, raptors' various flight capabilities ranging from slow silent flight through effortless soaring over great areas to incredibly fast stoops enable them to locate and/or catch their prey (Savile 1957, Ferguson-Lees & Christie 2001).

1.2 Overall diet composition of predatory raptors

Raptors can hunt a wide variety of animals. Prey animals are usually vertebrates including fish, amphibians, reptiles, mammals, and birds although various invertebrates are also hunted by some raptor species (del Hoyo et al. 1994, Ferguson-Lees & Christie 2001, Wilman et al. 2014). Individual raptor species are able to hunt a specific spectrum of prey animals depending, among other factors, on their body size. Generally, larger raptors can hunt larger prey (e.g. Comey & Dayan 2018). However, some relatively large raptors may mostly hunt small prey (as further discussed below). Moreover, raptors' diet composition also depends on prey availability (Ferguson-Lees & Christie 2001).

Diet composition usually reflects the environment inhabited by individual raptor species. Therefore, fish can often be found in the diet of raptors living near coastlines or inland water bodies. Amphibians may be preyed upon by raptors occupying marshland and tropical rainforests, whilst reptiles are often an important part of diet of raptors living in arid areas. Mammals and birds can be found in various types of environments, so they are preyed upon by many raptors inhabiting the same areas (Ferguson-Lees & Christie 2001). However, the range of prey types taken by each raptor species also depends on their individual evolutionary histories affecting their specific adaptations.

1.3 Generalist predatory raptors

Many raptors are generalists capable of hunting a wide range of prey and living in various environments. For example, the Red-tailed Hawk *Buteo jamaicensis* may prey upon mammals, birds, reptiles, amphibians, fish, and invertebrates, and it inhabits various habitats throughout

North America (Sherrod 1978, Ferguson-Lees & Christie 2001). Moreover, the Golden Eagle *Aquila chrysaetos* hunts various mammals from voles *Microtus* spp. and mustelids (Mustelidae) to small deer (Cervidae), birds from larks (Alaudidae) and thrushes (Turdidae) to geese, swans (Anserini), and cranes (Gruidae), and various reptiles including tortoises (Testudinidae, Ferguson-Lees & Christie 2001, Clouet et al. 2017). It can be found within many types of environment in the Holarctic realm (Ferguson-Lees & Christie 2001). However, some raptors are adapted for hunting a specific type of prey, often in specific environmental settings, resulting in diet specialization.

1.4 Predatory raptors' diet specialization

1.4.1 Invertebrate-eating raptors

Although the majority of raptors mostly rely on vertebrate prey, some raptors (e.g. the Snail Kite *Rostrhamus sociabilis*, honey buzzards *Pernis* spp.) are specialized in hunting invertebrates (Ferguson-Lees & Christie 2001). The Snail Kite feeds almost exclusively on apple snails *Pomacea* spp., and it has exceptionally long and thin beak and talons which help with the procurement of its prey (Snyder & Kale 1983, Ferguson-Lees & Christie 2001). Honey buzzards feed mostly on larvae, pupae, combs, and adults of social wasps, bees, and hornets. They have relatively small beaks and straighter talons compared to most of other raptors which facilitate digging insect nests from the ground (Ferguson-Lees & Christie 2001). Moreover, they have scale-like feathers on their foreheads and around eyes and slit-like nostrils. These adaptations may help to protect them against the insects fiercely protecting their nests (Sievwright & Higuchi 2011, Roberts & Law 2014).

1.4.2 Fish-eating raptors

Piscivorous raptors (e.g. the Osprey *Pandion haliaetus*, sea eagles *Icthyophaga* spp.) have particularly long and sharp talons and spicules (i.e. short, sharp spines) on the underside of their toes providing a firm grip on a fish (Ferguson-Lees & Christie 2001, Einoder & Richardson 2007, Fowler et al. 2009, Tsang et al. 2019). Ospreys also have reversible fourth toe, closeable nostrils and oily plumage preventing soaking. They are also able to hover, which helps them with finding potential prey (Ferguson-Lees & Christie 2001, Corvidae et al. 2006).

1.4.3 Reptile-eating raptors

Raptors with high proportion of reptiles in their diet (e.g. snake eagles *Circaetus* spp.) tend to have short but strong toes and relatively short talons helping them to hold thin reptiles such as lizards and snakes. They are usually relatively large compared to the size of their prey (Ferguson-Lees & Christie 2001). This is probably because they do not need to rely on manoeuvrability while hunting. Moreover, some species (e.g. the Short-toed Snake Eagle *Circaetus gallicus*) can hover while searching for prey (Bakaloudis 2010).

1.4.4 Mammal-eating raptors

Raptors specializing in hunting mammals usually hunt either small mammals (mostly rodents Rodentia) or relatively large and dangerous mammals (e.g. primates, sloths Folivora, small ungulates). Raptors hunting mostly small mammals (e.g. some buzzards *Buteo* spp., many owl species) usually have relatively short toes and talons facilitating a firm grip on small prey (Ferguson-Lees & Christie 2001). Some buzzards can also hover while searching for prey on the ground (Ferguson-Lees & Christie 2001). Owls' ability to fly extraordinarily slowly and silently enables them to surprise unaware prey (Geyer et al. 2013). Although many mammal-eating owls are relatively small, buzzards are relatively large birds despite their small prey (Ferguson-Lees & Christie 2001). Large buzzards can hunt small prey on the ground since they do not need to be highly manoeuvrable similarly to the snake eagles. Since small mammals usually swiftly hide in burrows when threatened, raptors have very little time for pursuing them. Therefore, the key factor affecting hunting success is the moment of surprise, which is usually achieved by quick short stoops on unsuspecting prey from a perch or flight (Ferguson-Lees & Christie 2001).

Raptors hunting mostly relatively large mammals (e.g. the Harpy Eagle *Harpia harpyja*, Crowned Eagle *Stephanoaetus coronatus*) are big with strong feet and exceptionally large talons facilitating quick killing of large and potentially dangerous prey (Ferguson-Lees & Christie 2001, Einoder & Richardson 2007). Although relatively large mammals can be found within many environments throughout the world, raptors hunting predominantly relatively large mammals usually inhabit tropical regions (Ferguson-Lees & Christie 2001).

1.4.5 Bird-eating raptors

Raptors predominantly hunting birds (e.g. some hawks *Accipiter* spp., eagles *Spizaetus* spp., falcons *Falco* spp.) usually have long toes with relatively short talons (Einoder & Richardson 2007, Fowler et al. 2009). Long toes provide better reach helping with catching aerial prey, and they also help with reaching through prey birds' plumage enabling a firm grip directly on their bodies (Newton 1986, Ferguson-Lees & Christie 2001, Einoder & Richardson 2007). This is crucial for successful bird hunting since many birds may lose their feathers (particularly contour feathers) when they are pulled (Møller et al. 2006). Therefore, if a raptor holds a bird only by its feathers it may end up with a grip full of feathers and a prey flying away. On the other hand, bird-eating raptors do not need particularly large talons because birds have relatively thin skin, which can be easily penetrated, and are relatively fragile compared to similarly sized mammals. Therefore, birds are usually easier to subdue and kill compared to similarly sized mammals (Einoder & Richardson 2007). Moreover, the body size of bird-eating raptors is more closely related to the size of their prey compared to raptors hunting mammals or reptiles on the ground. Since smaller birds are generally more agile and manoeuvrable than larger ones, large raptors cannot hunt small birds effectively (Mendelsohn 1986, Newton 1986). This is probably the reason why bird-eating raptors have particularly pronounced sexual dimorphism in size (males in some species are up to 50% smaller than females) because it enables them to hunt a wide size range of bird species during breeding reducing intersexual food competition (Temeles 1985). Furthermore, hunting birds in different environments (e.g. forests, open areas) requires different hunting methods. Therefore, bird-eating raptors also have specific adaptations depending on the environment where they hunt.

Bird-eating raptors hunting in open areas (e.g. some falcons) usually have relatively long, narrow, and pointy wings, relatively short tails, and relatively short but strong legs (Einoder & Richardson 2007, Fowler et al. 2009). These adaptations enable them to achieve extraordinarily high speed in both horizontal flight and stoops and to withstand collisions with prey at high speed (Savile 1957, Einoder & Richardson 2007). Moreover, they can maintain high speed in horizontal flight for relatively long time periods and over long distances (Savile 1957). Birds living in open areas are usually fast fliers depending on their speed and manoeuvrability rather than seeking cover while evading predators. Therefore, falcons' ability to fly fast over long distances is crucial for catching their prey because it enables them to outfly the prey in horizontal flight or to stoop at it at high speed from above (Dekker 1980).

Conversely, bird-eating raptors hunting primarily in forests (e.g. some hawks) usually have relatively short, wide, rounded wings, long tails, and relatively long legs (Einoder & Richardson 2007, Fowler et al. 2009). The shape and size of their wings and tails enable hawks to be highly manoeuvrable (Savile 1957, Corvidae et al. 2006). The relatively long, slender but strong legs enable them not only to generate substantial speed by jumping from a perch or the ground but also to pursue their prey on the ground. Moreover, long legs also increase reach for grasping prey (Newton 1986, Einoder & Richardson 2007). Although hawks are not able to achieve as high speeds as falcons and to maintain their maximum speed for long time periods, they can rapidly accelerate even from a perched position (Lockwood et al. 1998). Since forests are complex environment with many various terrain features (e.g. trees, undergrowth), forest birds often try to seek cover and rely on their manoeuvrability while evading predators. Therefore, hawks usually have less time for pursuing prey compared to falcons. Thus, their high agility and manoeuvrability enable hawks to surprise prey and to quickly pursue it through areas with limited space, which is crucial for successful hunting (Newton 1986).

1.5 Bird-eating raptors' diet composition and prey selection

Although raptors specializing in hunting birds often hunt a wide variety of species, some prey species may be more important compared to others forming a substantial part of raptors' diet (e.g. Newton et al. 1984, Newton 1986). Diet composition is based on available food supply (i.e. bird community) which may differ between different areas according to their habitat composition (Newton 1986, Bibby 1987). Therefore, different prey species may be important in different populations of the same raptor species (e.g. Falk et al. 1986, Dixon & Drewitt 2018, Palmer et al. 2019). However, some prey species may be more preferred than others in relation to their occurrence in food supply (e.g. Selås 1993, Götmark & Post 1996, Solonen 1997, Solonen 2000). This suggests that raptors may select their prey.

Prey selection may be affected by individual prey species' behaviour since it may affect their conspicuousness in an environment and it may also affect raptors' hunting success (Newton 1986, Selås 1993). Other prey species characteristics may also affect raptors' hunting preferences including prey body size, abundance, and plumage colouration (Petty et al. 1995, Götmark & Post 1996, Rytkönen et al. 1998). Prey species body size affects raptors' hunting profitability, and their abundance affects the frequency of encounters with raptors (Opdam 1978, Petty et al. 1995). Similarly to prey behaviour, prey species plumage colouration may

affect their conspicuousness (Ruiz-Rodríguez et al. 2013). However, raptors' prey selection may also be based on each raptor's unique hunting experience. For example, individual raptors may use slightly different hunting methods and may search for prey within different areas based on their hunting success. This may result in preference for prey species that are efficiently caught using their favoured hunting method and in more frequent encounters of a specific subset of prey species living within their hunting areas (Newton 1986, Solonen 2000).

2 Aims

The aim of this study is to describe diet composition of the Eurasian Sparrowhawk *Accipiter nisus* (hereafter 'Sparrowhawk') in relation to the food supply, land cover (i.e. habitat composition), and several prey species characteristics in Pošumaví. To address this objective, following hypotheses were tested. (1) The structure of land cover in Sparrowhawk hunting areas determines the structure of food supply. (2) The structure of land cover in Sparrowhawk hunting areas affects their diet composition. (3) Sparrowhawks do not hunt individual prey species proportionally to their occurrence in food supply (i.e. Sparrowhawks prefer some prey species more than others). (4) Sparrowhawk prey selection is based on prey species body mass, abundance, and plumage colouration. (5) Diet composition of closely located Sparrowhawk breeding pairs is more similar compared to more distant pairs (i.e. the similarity of diet composition of Sparrowhawk breeding pairs decreases with increasing geographical distance between them).

3 Methods

3.1 Study species

The Sparrowhawk is a small raptor living throughout Europe and temperate Asia. It is primarily a woodland bird (Cramp 1980, del Hoyo et al. 1994), but it has also settled in cities (Biaduń 2006, Papp 2011, Schütz & Schulze 2018). With its short, broad wings and long tail the Sparrowhawk is extremely agile and manoeuvrable for its size. Moreover, it has long legs and particularly long toes with needle-sharp talons helping with hunting its main prey (Newton 1986). Its diet is mostly composed of birds (Cramp 1980, Newton 1986, Selås 1993, Zawadzka & Zawadzki 2001, Bujoczek & Ciach 2009, Rodríguez et al. 2020). Many bird species within a wide range of sizes, ranging from the smallest passerines to the Wood Pigeon *Columba palumbus*, can be regularly preyed upon by Sparrowhawks (Newton & Marquiss 1982). Sparrowhawks can utilise a variety of hunting tactics. However, they usually tend to surprise their prey by short distance ambush attacks from vegetation cover using various terrain features and their superb agility and manoeuvrability (Newton 1986).

3.2 Study area

Sparrowhawks' diet was studied within a study area (330 km^2) located in South Bohemia, the Czech Republic (48.72N, 14.18E). The study area was located in the foothills of the Šumava Mountains, and its eastern, southern and western borders were mainly represented by the Vltava River and the Lipno Reservoir. The terrain was hilly with moderate slopes, shallow valleys and elevation ranging from 500 to 1200 m a.s.l.

The land cover comprised forest areas (50.3%), agricultural areas (43.4%), semi-natural areas (0.9%), artificial surfaces (4.3%), wetlands (0.4%) and water bodies (0.7%, ZABAGED, Czech Office for Surveying, Mapping and Cadastre ČÚZK 2024). The forest areas consisted of coniferous (69.8%), mixed (20.5%) and broad-leaved (9.7%) forests. The dominant coniferous species were the Norway Spruce *Picea abies*, Scots Pine *Pinus sylvestris*, European Silver Fir *Abies alba* and European Larch *Larix decidua*. The broad-leaved species mostly included 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. The forests were regularly distributed throughout the study area, and their sizes varied from small patches

(< 1 ha) to large forests extending over more than 20 km^2. The agricultural areas were mostly represented by pastures and meadows with a small proportion of arable land. The semi-natural areas consisted mostly of shrublands with shrubs such as the Common Hazel *Corylus avellana*, Blackthorn *Prunus spinosa* and Grey Willow *Salix cinerea*. The artificial surfaces consisted of villages and several small towns scattered over the study area. The wetlands comprised peat bogs and inland marshes, and the water bodies included small streams and several ponds.

The bird community within the study area reflected the available habitats and the upland position of the study area. Therefore, although it consisted of a wide range of species, some farmland and lowland species were eighter rare or absent.

3.3 Data collection

3.3.1 Diet composition

The data on Sparrowhawk diet composition were collected during the breeding seasons 2023 and 2024. Additionally, data on Sparrowhawk diet gathered during breeding seasons 2019 – 2022 were included into the dataset (Dvořák 2022). The data were collected using prey remains (e.g. plucked feathers, fur) discarded by Sparrowhawks during preparation of prey for consumption. The plucked remains were found at plucking sites in the vicinity of Sparrowhawk nests. Plucked feathers found far away from the nests were not included because it was unclear which predator plucked them due to the presence of other bird eating raptors such as Northern Goshawks *Accipiter gentilis*, Tawny Owls *Strix aluco* and Pygmy Owls *Glaucidium passerinum* within the study area. Only fresh feathers (up to about two weeks old) that were readily distinguishable were included. The time for which the visual quality of feathers remains high depends on weather conditions, especially on the occurrence of precipitation. Older feathers, particularly those from small species, which were exposed to rain may be difficult not only to distinguish but also to find. Therefore, using only fresh feathers decreased the probability of the occurrence of an undesirable bias towards larger species. The nest sites were regularly visited throughout the breeding seasons (at least once every two weeks), and individual prey items were recorded. Individual birds belonging to the same species found simultaneously were distinguished by counting flight feathers (primaries, rectrices).

Other prey remains such as bony remains and pellets were not included into the dataset on Sparrowhawk diet. Since Sparrowhawks often eat small birds completely, bony remains

usually consist of bones from large species (Newton 1986). Therefore, bony remains offer an unrepresentative view on the diet. Sparrowhawk pellets are generally made of small contour and down feathers. These have similar shapes and sizes in many different species and are mostly greyish with different colouration only at the top of contour feathers. Therefore, their use for prey species determination may not be appropriate. Occasionally, claws and bills, whose origin may be identified, may also be found inside of pellets. However, pellets were rarely found and therefore represented an insufficient data resource. Moreover, the simultaneous use of plucked feathers and pellets can cause counting of the same individual twice.

Some prey species were difficult to identify because of their resemblance. Therefore, prey items from such species were grouped as follows. The Willow Tit *Poecile montanus* with the Marsh Tit *Poecile palustris*, the Goldcrest *Regulus regulus* with the Common Firecrest *Regulus ignicapilla*, the Common Chiffchaff *Phylloscopus collybita* with the Willow Warbler *Phylloscopus trochilus* and Wood Warbler *Phylloscopus sibilatrtix*, and the Black Redstart *Phoenicurus ochruros* with the Common Redstart *Phoenicurus phoenicurus*. Moreover, the sex of prey items from dimorphic species was only rarely possible to distinguish (only from ideal plucking sites with lots of contour feathers). Therefore, the sex of prey items from dimorphic species was not recorded. Of the mammalian prey species, only the Bank Vole *Clethrionomys glareolus* was possible to identify because of its distinctively red tinged fur. Therefore, prey items belonging to other mammals were classified as small mammals.

3.3.2 Food supply

The abundance of birds around the Sparrowhawk nests was estimated using the point count method (Dawson 1981). Five counting points were selected at the minimum distance from each other of 200 m within a 1 km radius around each nest. The area of this size around a nest should be within Sparrowhawk home ranges based on the distances from nests travelled by breeding Sparrowhawks (Marquiss and Newton 1982). The counting points were localised at sites with vegetation potentially providing Sparrowhawks with opportunities for ambushing their prey (e.g. forest margins, forests, shrubs). At each counting point, every bird individual seen or heard within an area of a 100 m radius and during a 10 min period was counted except for species larger than the Wood Pigeon that are not regularly hunted by breeding Sparrowhawks (Newton & Marquiss 1982). Bird counting was executed during appropriate

weather conditions (i.e. without precipitation and strong wind) and twice at each counting point from May to June (6:00 – 11:00 hours).

3.3.3 Land cover and prey species characteristics

For each counting point and each nest, percentages of individual land cover categories within a buffer of 100 m and 1 km radius respectively were calculated using land cover data from ZABAGED (ČÚZK 2024).

To describe body sizes of the prey species, mean avian body masses listed by Dunning (2008) were used. For the species with different body masses between the sexes, mean values were calculated. For the Bank Vole and other small mammals, the body mass of 25 g was used.

Prey species colouration was assessed using high quality photographs of perched birds available on www.birdphoto.cz. Colouration was assessed using following categories: inconspicuous (e.g. green, brown), intermediate (e.g. grey, beige, pink), and conspicuous (e.g. red, black, white). The categories were given scores 1, 2, and 3 respectively. Colouration was scored for the anterior (head and neck), middle (most of the torso and wings), and posterior (rump, undertail coverts, tail) body parts separately. Moreover, the colouration of the dorsal and ventral sides of each body part was scored separately. The final species scores were calculated in two different ways. Firstly, the colouration of both sexes of each species was scored separately, and individual scores were summed forming final species scores (Table S1). Secondly, the colouration of both sexes of dimorphic species was scored separately and the colouration of species without sexual dimorphism in plumage colouration was scored for only one individual representing either sex (Table S2). These two ways of calculating plumage colouration scores provided different representations of plumage colouration. The first way provided one score for each prey species which corresponded to one vulnerability index value for each species (see the text below). However, the scores of dimorphic species were inaccurate because they did not represent either sex properly. The second way provided more accurate representation of the plumage colouration of the sexes of dimorphic species, but it required the use of the same vulnerability index value for both sexes (see the text below).

3.4 Statistical analyses

The relationship between the food supply or Sparrowhawk diet (i.e. dependent variables) and percentages of land cover categories within the buffers around the counting points and

Sparrowhawk nests (i.e. independent variables or primary predictors) was tested 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 analysis facilitated the removal of the effect of geographical position (i.e. space predictors) from the effect of primary predictors (Legendre & Legendre 2012). The analysis is suitable for computing inter-correlated variables since all the variables enter the analysis simultaneously. The analysis consisted of 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).

The first PCNM analysis was executed with the food supply (percentages of individual bird species calculated from maximal abundances of the species recorded during the consecutive counts at each counting point, i.e. dependent variables, n = 70 species) and with percentages of land cover categories within a buffer of 100 m radius around each counting point (i.e. primary predictors). A total of 310 counting points were used for this analysis. For the second PCNM analysis, prey items found around nests from different breeding seasons within the same breeding territories (i.e. small areas used for building nests) were combined into datasets representing repeatedly used territories. Therefore, the samples used for this analysis were represented by individual territories some of which were used repeatedly in different breeding seasons (15 territories, 8 of them were used three times, 7 of them were used twice). Before the second PCNM analysis, a principal component analysis (PCA) with land cover within a buffer of 1 km radius around each territory was performed to calculate correlations among individual land cover categories. Subsequently, the second PCNM analysis was performed with percentages of individual bird species found among prey items within the territories (i.e. dependent variables, n = 47 species) and with percentages of land cover categories within a buffer of 1 km radius around each territory (i.e. primary predictors). Only

territories with a minimum of 15 prey items were used for this analysis (21 territories). Before both analyses, the percentage data were arcsine transformed.

Sparrowhawks' hunting preference for individual bird species based on their occurrence in the diet and food supply was analysed by comparing percentages of individual bird species found among the prey items and recorded in the food supply using compositional analysis of habitat use (function compana, package adehabitatHS) in R 4.4.1 software (R Core Team 2024). For each nest, percentages of each species in the diet and food supply (i.e. mean numbers of individuals recorded at the counting points) were calculated. Zero values were replaced by 0.01 (Aebischer et al. 1993). Only bird species representing at least 0.1% of the total food supply within the study area (37 species) and only nests around which at least 10 prey items were found (39 nests) were included into this analysis. This analysis was executed in two steps. Firstly, the significance of prey species use was tested using Wilks lambda. Secondly, a ranking matrix was built indicating whether the species in the row was used significantly more or less than the species in the column. Moreover, the bird species were sorted from most preferred to non-preferred (Aebischer et al. 1993).

To test the effect of several prey species characteristics (body mass, abundance, and colouration) on Sparrowhawk prey selection, vulnerability index (Newton 1986) for each prey species was calculated by dividing percentages of individual prey species in the diet by their percentages in the total food supply. If the vulnerability index was equal to 1, the species occurred in the diet proportionally to the food supply. If the vulnerability index was < 1, the species was under-represented in the diet, and if the vulnerability index was > 1, the species was over-represented in the diet compared to the food supply. Since the sex of the prey items was not recorded, the vulnerability indices were possible to calculate only for the species and not for the sexes separately. Subsequently, the effects of prey species characteristics on their vulnerability indices were tested using polynomial (body mass) and linear (abundance, colouration, colouration with the sexes of dimorphic species separated) regressions in Statistica 14.0 software (TIBCO software Inc. 2020). The abundance of each species was represented by its mean percentage in the total food supply. Only bird species representing at least 0.1% of the total food supply in the study area (37 species) were included into these analyses. However, for the analysis of the effect of prey species colouration on their vulnerability with the sexes of dimorphic species separated, the separated sexes were treated as individual species resulting in 46 species used in this analysis. Moreover, the same vulnerability index was used for both sexes of the dimorphic species. Before the analyses, the vulnerability index, body mass, and abundance were log transformed.

The effect of geographical distance on similarity of the diet of individual Sparrowhawk pairs was tested by comparing distances between all the nests (62 nests) and indices of diet overlap between all the pairs using a Mantel test in PASSaGE 2 software (Rosenberg & Anderson 2011) and linear regression in Statistica 14.0 software. The distances between individual nests were calculated using Near tool in ArcGIS pro (Esri). Diet overlap was computed using niche overlap index (Pianka 1974) in R 4.4.1 software (function niche.overlap, package spaa).

4 Results

4.1 The effect of land cover on food supply

The PCNM analysis of variance partitioning for food supply showed that 12.6% of the total variability was explained, 10.2% was explained by the primary predictors, 1.1% was explained by the space predictors and 1.3% accounted for the shared fraction. The structure of food supply (i.e. percentages of individual bird species recorded at the counting points) was significantly linked with five primary predictors (i.e. percentages of land cover categories within buffers of 100 m radius around the counting points). These were coniferous forests, grassland, artificial surfaces, mixed forests, and broad-leaved forests (Table 1). After removing the spatial effects, the primary predictors were correlated with the ordination axes as follows (Figure 1). Percentages of coniferous forests were negatively correlated mainly with the first ordination axis ($r_1 = -0.80$) and weakly with the second ordination axis ($r_2 = -0.07$). Percentages of mixed forests ($r_1 = 0.17$, $r_2 = 0.29$), broad-leaved forests ($r_1 = 0.35$, $r_2 = 0.36$), and artificial surfaces ($r_1 = 0.30$, $r_2 = 0.09$) were positively correlated with both ordination axes. Percentages of grassland were positively correlated with the first ordination axis and negatively correlated with the second ordination axis ($r_1 = 0.72$, $r_2 = -0.28$). The dependent variables (i.e. percentages of each bird species) showed following correlations (Figure 1). Negatively correlated with both ordination axes were the Goldcrest, Coal Tit *Periparus ater*, Crested Tit *Lophophanes cristatus*, Common Chaffinch *Fringilla coelebs*, and Eurasian Treecreeper *Certhia familiaris*. Negatively correlated with the first ordination axis and positively correlated with the second ordination axis were the Eurasian Wren *Troglodytes troglodytes*, European Robin *Erithacus rubecula*, and Common Chiffchaff. Positively correlated with both ordination axes were the Eurasian Blackcap *Sylvia atricapilla*, Willow Warbler, Spotted Flycatcher *Muscicapa striata*, Garden Warbler *Sylvia borin*, Blue Tit *Cyanistes caeruleus*, European Greenfinch *Chloris chloris*, Great Tit *Parus major*, and Black Redstart. Positively correlated with the first ordination axis and negatively correlated with the second ordination axis were the Eurasian Magpie *Pica pica*, Common Whitethroat *Curruca communis*, White Wagtail *Motacilla alba*, Barn Swallow *Hirundo rustica*, European Green Woodpecker *Picus viridis*, Common Starling *Sturnus vulgaris*, Yellowhammer *Emberiza citrinella*, Eurasian Skylark *Alauda arvensis*, Tree Pipit *Anthus trivialis*, European Goldfinch *Carduelis carduelis*, Red-backed Shrike *Lanius collurio*, Common Quail *Coturnix coturnix*, Woodlark *Lullula arborea*, and House Sparrow *Passer domesticus* (Table 2).

Table 1. The effect of the primary and space predictors on the variability in the food supply (PCNM analysis, n = 70 bird species from 310 counting points).

Predictor	Contribution (%)	pseudo - F	P
Primary predictors:			
Coniferous forests	53.69	31.0	0.002
Grassland	10.47	6.2	0.002
Artificial surfaces	5.18	3.1	0.002
Mixed forests	3.68	2.2	0.002
Broad-leaved forests	2.88	1.7	0.022
Space predictors:			
PCO.20	2.89	3.1	0.002
PCO.52	2.81	3.0	0.002
PCO.13	2.55	2.8	0.002
PCO.18	2.15	2.4	0.002

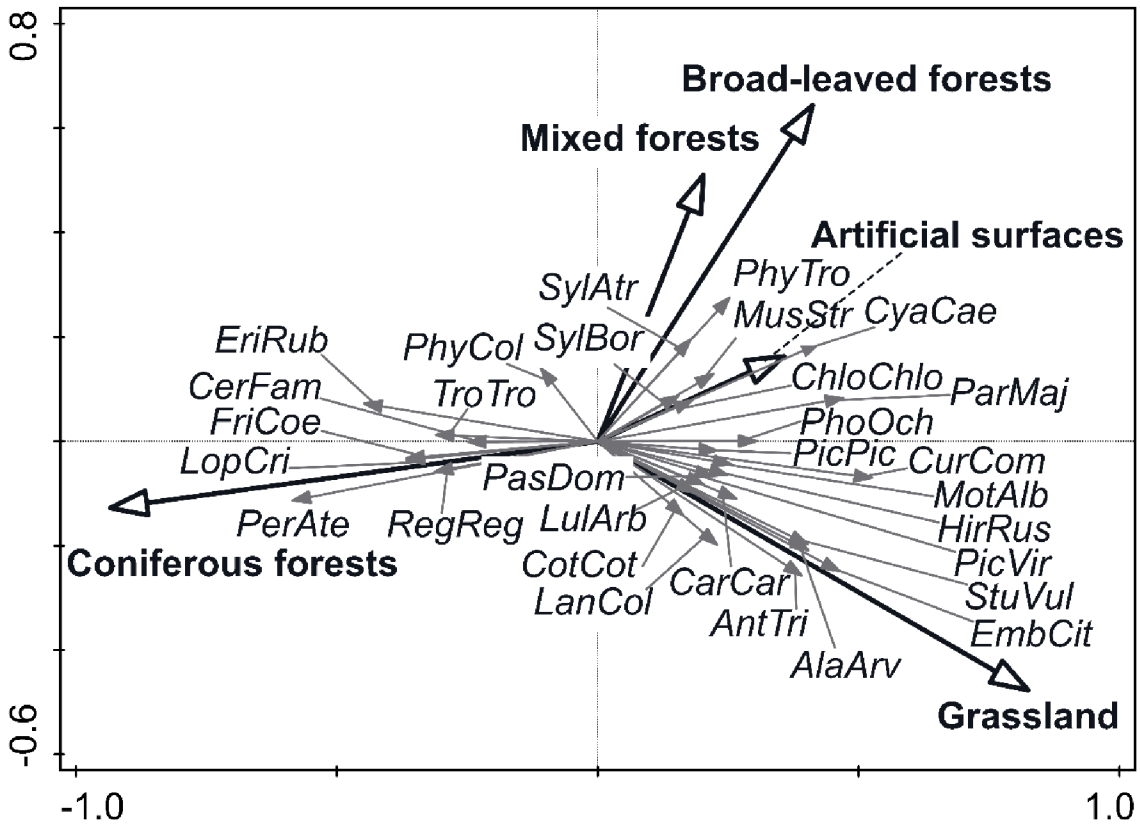

Figure 1. The projection scores for the primary predictors (i.e. percentages of land cover categories) and dependent variables (i.e. percentages of individual bird species, n = 70 species) in the surroundings (a 100 m radius) of the 310 counting points (from the vicinity of 62 nests)

after removing the spatial effects. PCNM analysis, I. and II. ordination axes together explained 10.5% of the variability. Only species fitting at least 3% on both ordination axes are displayed (30 species). The black hollow arrows represent the primary predictors. The grey arrows represent dependent variables. The explanation of the species abbreviations: *AlaArv = Alauda arvensis, AntTri = Anthus trivialis, CarCar = Carduelis carduelis, CerFam = Certhia familiaris, ChloChlo = Chloris chloris, CotCot = Coturnix coturnix, CurCom = Curruca communis, CyaCae = Cyanistes caeruleus, EmbCit = Emberiza citrinella, EriRub = Erithacus rubecula, FriCoe = Fringilla coelebs, HirRus = Hirundo rustica, LanCol = Lanius collurio, LopCri = Lophophanes cristatus, LulArb = Lullula arborea, MotAlb = Motacilla alba, MusStr = Muscicapa striata, ParMaj = Parus major, PasDom = Passer domesticus, PerAte = Periparus ater, PhoOch = Phoenicurus ochruros, PhyCol = Phylloscopus collybita, PhyTro = Phylloscopus trochilus, PicPic = Pica pica, PicVir = Picus viridis, RegReg = Regulus regulus StuVul = Sturnus vulgaris, SylAtr = Sylvia atricapilla, SylBor = Sylvia borin, TroTro = Troglodytes troglodytes.*

Table 2. The correlation coefficients with both ordination axes for individual species from the PCNM analysis of the effect of land cover on food supply. The species are in the same order as they are listed in the text.

Species	r_1	r_2
Regulus regulus	−0.31	−0.06
Periparus ater	−0.59	−0.11
Lophophanes cristatus	−0.37	−0.04
Fringilla coelebs	−0.37	−0.03
Certhia familiaris	−0.25	−0.001
Troglodytes troglodytes	−0.31	0.01
Erithacus rubecula	−0.45	0.07
Phylloscopus collybita	−0.11	0.14
Sylvia atricapilla	0.18	0.20
Phylloscopus trochilus	0.25	0.28
Muscicapa striata	0.22	0.13
Sylvia borin	0.16	0.09
Cyanistes caeruleus	0.43	0.19
Chloris chloris	0.18	0.08
Parus major	0.47	0.08
Phoenicurus ochruros	0.31	0.001
Pica pica	0.22	−0.02
Curruca communis	0.53	−0.07
Motacilla alba	0.26	−0.04
Hirundo rustica	0.25	−0.06
Picus viridis	0.22	−0.07

Sturnus vulgaris	0.40	−0.20
Emberiza citrinella	0.46	−0.25
Alauda arvensis	0.40	−0.21
Anthus trivialis	0.39	−0.26
Carduelis carduelis	0.27	−0.11
Lanius collurio	0.23	−0.20
Coturnix coturnix	0.16	−0.14
Lullula arborea	0.19	−0.10
Passer domesticus	0.20	−0.08

4.2 Diet composition

A total of 1107 prey items were recorded around 62 nests (range = 1 – 93 prey items, mean = 17.9 prey items ± 16.8 SD) from 39 different breeding territories. The diet consisted mostly of birds (98.9% of prey items, 99.5% of biomass) with a small proportion of mammals (1.1% of prey items, 0.5% of biomass). Only five species represented at least five percent of the prey items, namely the Common Blackbird *Turdus merula* (16.3%), Song Thrush *Turdus philomelos* (15.7%), Common Chaffinch (10.9%), European Robin (6.6%), and Great Tit (5.8%). Moreover, more than three quarters (77.6%) of the prey biomass was represented by only six species, namely the Common Blackbird (32.1%), Song Thrush (18.6%), Wood Pigeon (10.8%), Common Starling (6.9%), Eurasian Jay *Garrulus glandarius* (4.8%), and Great Spotted Woodpecker *Dendrocopos major* (4.4%). For the contribution of each prey species to the diet see Supplementary material (Table S3).

4.3 The effect of land cover on diet composition

The PCA analysis for percentages of land cover categories within 1 km buffers around selected breeding territories revealed following correlations (Figure 2). Percentages of grassland were negatively correlated with both ordination axes ($r_1 = -0.94$, $r_2 = -0.26$). Percentages of shrubs ($r_1 = -0.48$, $r_2 = 0.27$), artificial surfaces ($r_1 = -0.43$, $r_2 = 0.57$), and arable land ($r_1 = -0.06$, $r_2 = 0.83$) were negatively correlated with the first ordination axis and positively correlated with the second ordinations axis. Percentages of forests were positively correlated with the first ordination axis and negatively correlated with the second ordination axis ($r_1 = 0.98$, $r_2 = -0.12$).

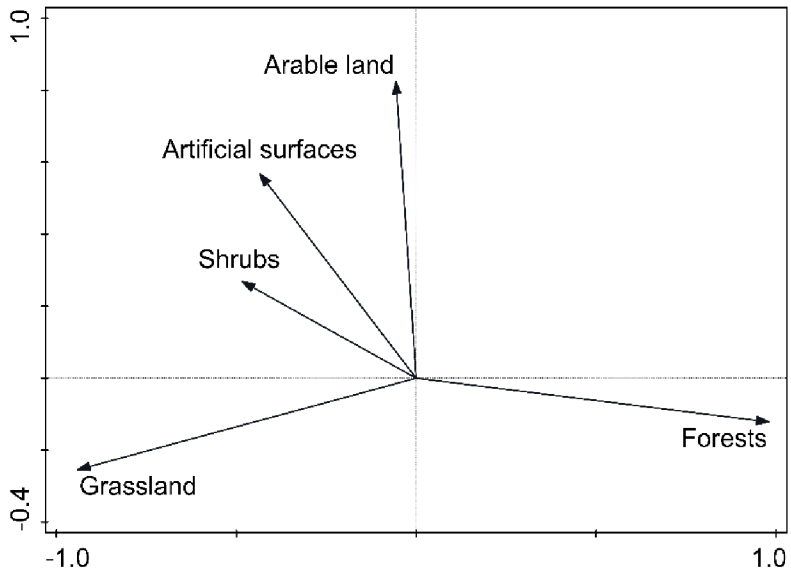

Figure 2. The correlations between the percentages of land cover categories within surroundings of the breeding territories (a 1 km radius). The arrows represent individual land cover categories. PCA analysis, I. and II. ordination axes together explained 87.9% of variability (n = 21 breeding territories).

The PCNM analysis of variance partitioning for diet composition showed that 6.9% of the total variability was explained by this analysis. 4.5% was explained by the primary predictors, 0.2% was explained by the space predictor and 2.2% accounted for the shared fraction. The diet composition (i.e. percentages of each bird species found among the prey items) was significantly linked with two primary predictors (i.e. percentages of land cover categories within 1 km buffers around the selected breeding territories), namely percentages of artificial surfaces and forests (Table 3). After removing the spatial effects, the primary predictors showed following correlations (Figure 3). Percentages of forests were negatively correlated with both ordination axes ($r_1 = -0.79$, $r_2 = -0.26$). Percentages of artificial surfaces were positively correlated with the first ordination axis and negatively correlated with the second ordination axis ($r_1 = 0.68$, $r_2 = -0.49$). The dependent variables (i.e. percentages of individual bird species in the diet) showed following correlations (Figure 3). Negatively correlated with both ordination axes were the Great Tit, Tree Pipit, Common Blackbird, European Pied Flycatcher *Ficedula hypoleuca*, and Song Thrush. Negatively correlated with the first ordination axis and positively correlated with the second ordination axis were the Coal tit, Crested Tit, Great Spotted Woodpecker, Grey Wagtail *Motacilla cinerea*, and Eurasian Bullfinch *Pyrrhula pyrrhula*. Positively correlated with both ordination axes were the Mistle

Thrush *Turdus viscivorus*, Whinchat *Saxicola rubetra*, Barn Swallow, Woodlark, Eurasian Skylark, Yellowhammer, Black Redstart/Common Redstart, Common Whitethroat, House Sparrow, Red-backed Shrike, White Wagtail, and Lesser Redpoll *Acanthis cabaret*. Positively correlated with the first ordination axis and negatively correlated with the second ordination axis were the European Goldfinch, Common Starling, Common Linnet *Linaria cannabina*, Willow Tit/Marsh Tit, Wood Pigeon, Eurasian Collared Dove *Streptopelia decaocto*, Common House Martin *Delichon urbicum*, and Eurasian Jay (Table 4).

Table 3. The effect of the primary and space predictors on the variability in the diet (PCNM analysis, n = 47 bird species within 21 breeding territories).

Predictor	Contribution (%)	pseudo - F	P
Primary predictors:			
Artificial surfaces	19.1	1.8	0.012
Forests	15.5	1.5	0.046
Space predictor:			
PCO.3	23.4	1.5	0.034

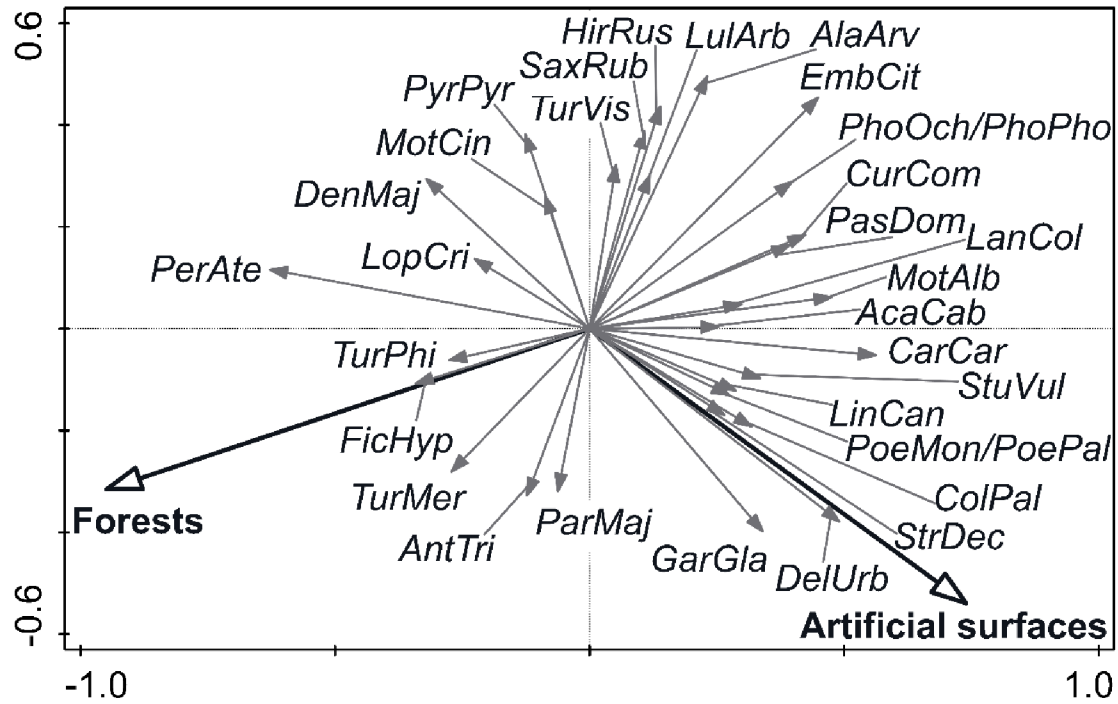

Figure 3. The projection scores for the primary predictors (i.e. percentages of land cover categories in the surroundings of the 21 breeding territories, a 1 km radius) and dependent

variables (i.e. percentages of prey items from individual bird species in the diet, n = 47 species within 21 breeding territories) recorded for the selected breeding territories with removed spatial effects. PCNM analysis, I. and II. ordination axes together explained 14.7% of the variability. Only species fitting at least 6.4% on both ordination axes are displayed (30 species). The black hollow arrows represent the primary predictors. The grey arrows represent dependent variables. The explanation of the species abbreviations: *AcaCab = Acanthis cabaret, AlaArv = Alauda arvensis, AntTri = Anthus trivialis, CarCar = Carduelis carduelis, ColPal = Columba palumbus, CurCom = Curruca communis, DelUrb = Delichon urbicum, DenMaj = Dendrocopos major, EmbCit = Emberiza citrinella, FicHyp = Ficedula hypoleuca, GarGla = Garrulus glandarius, HirRus = Hirundo rustica, LanCol = Lanius collurio, LinCan = Linaria cannabina, LopCri = Lophophanes cristatus, LulArb = Lullula arborea, MotAlb = Motacilla alba, MotCin = Motacilla cinerea, ParMaj = Parus major, PasDom = Passer domesticus, PerAte = Periparus ater, PhoOch/PhoPho = Phoenicurus ochruros/Phoenicurus phoenicurus, PoeMon/PoePal = Poecile montanus/Poecile palustris, PyrPyr = Pyrrhula pyrrhula, SaxRub = Saxicola rubetra, StrDec = Streptopelia decaocto, StuVul = Sturnus vulgaris, TurMer = Turdus merula, TurPhi = Turdus philomelos, TurVis = Turdus viscivorus.*

Table 4. The correlation coefficients with both ordination axes for individual species from the PCNM analysis of the effect of land cover on diet composition. The species are in the same order as they are listed in the text.

Species	r_1	r_2
Parus major	−0.06	−0.32
Anthus trivialis	−0.12	−0.33
Turdus merula	−0.27	−0.28
Ficedula hypoleuca	−0.34	−0.11
Turdus philomelos	−0.28	−0.06
Periparus ater	−0.63	0.12
Lophophanes cristatus	−0.23	0.14
Dendrocopos major	−0.32	0.29
Motacilla cinerea	−0.09	0.26
Pyrrhula pyrrhula	−0.13	0.38
Turdus viscivorus	0.05	0.32
Saxicola rubetra	0.11	0.39
Hirundo rustica	0.14	0.44
Lullula arborea	0.12	0.30
Alauda arvensis	0.23	0.50
Emberiza citrinella	0.45	0.45
Phoenicurus ochruros/Phoenicurus phoenicurus	0.40	0.29
Curruca communis	0.42	0.18

Passer domesticus	0.39	0.16
Lanius collurio	0.30	0.05
Motacilla alba	0.48	0.06
Acanthis cabaret	0.25	0.004
Carduelis carduelis	0.56	−0.05
Sturnus vulgaris	0.34	−0.10
Linaria cannabina	0.29	−0.12
Poecile montanus/Poecile palustris	0.27	−0.13
Columba palumbus	0.32	−0.19
Streptopelia decaocto	0.27	−0.17
Delichon urbicum	0.49	−0.38
Garrulus glandarius	0.34	−0.40

4.4 Hunting preferences

The Sparrowhawks did not hunt individual prey species randomly with respect to their occurrence in the food supply (compositional analysis, $\lambda = 0.008$, $P = 0.034$). Some species occurred significantly more in the diet than others, and some species occurred significantly less in the diet than others (Table S4). Therefore, some species were preferred for hunting whilst others were less favoured (Table 5). The most preferred species were the Common Starling, Dunnock *Prunella modularis*, European Goldfinch, Song Thrush, and Common Blackbird. The least preferred species were the Goldcrest/Common Firecrest, Crested Tit, Common Chiffchaff/Willow Warbler/Wood Warbler, Eurasian Wren, and Wood Pigeon.

Table 5. The ranking of individual prey species (n = 37 species from the vicinity of 39 nests) derived from the comparison of their percentages in the diet and food supply. Higher ranking corresponds to higher preference for a particular species based on its occurrence in the diet and food supply (compositional analysis).

Species	**Ranking**
Sturnus vulgaris	36
Prunella modularis	35
Carduelis carduelis	34
Turdus philomelos	33
Turdus merula	32
Cyanistes caeruleus	31
Passes domesticus	30
Turdus pilaris	29
Lanius collurio	28
Hirundo rustica	27
Motacilla alba	26
Pica pica	25

Coccothraustes coccothraustes	24
Phoenicurus ochruros/Phoenicurus phoenicurus	23
Coturnix coturnix	22
Alauda arvensis	21
Fringilla coelebs	20
Spinus spinus	19
Parus major	18
Dendrocopos major	17
Poecile montanus/Poecile palustris	16
Emberiza citrinella	15
Curruca communis	14
Sitta europaea	13
Anthus trivialis	12
Erithacus rubecula	11
Periparus ater	10
Garrulus glandarius	9
Certhia familiaris	8
Sylvia atricapilla	7
Pyrrhula pyrrhula	6
Turdus viscivorus	5
Columba palumbus	4
Troglodytes troglodytes	3
Phylloscopus collybita/Phylloscopus trochilus/Phylloscopus sibilatrix	2
Lophopanes cristatus	1
Regulus regulus/Regulus ignicapilla	0

4.5 The effect of prey species characteristics on Sparrowhawk prey selection

Prey species body mass had significant effect on their vulnerability (polynomial regression, n = 37 species, $R^2_{adj} = 0.36$, $F = 11.26$, $P < 0.001$). The Sparrowhawks hunted prey in a wide body mass range (5.6 – 490 g), but they preferred prey species around the middle of the body mass range (Figure 4). The preferred range of prey body mass was approximately 15 – 200 g. Small and large prey species showed lower occurrence in the diet than expected from their abundance in the food supply.

Prey species' vulnerability decreased with their increasing abundance in the food supply (linear regression, n = 37 species, $R^2_{adj} = 0.114$, $F_{1,35} = 5.65$, $P = 0.023$, Figure 5). Moreover, prey species' vulnerability increased with increasing conspicuousness of their colouration (linear regression, n = 37 species, $R^2_{adj} = 0.076$, $F_{1,35} = 3.95$, $P = 0.049$, Figure 6). However, the significance of this relationship decreased when the sexes of the dimorphic species were tested separately (linear regression, n = 46 species, $R^2_{adj} = 0.042$, $F_{1,44} = 2.95$, $P = 0.093$, Figure 7).

4.6 The effect of geographical distance on inter-pair similarity of diet

No significant effect of geographical distance on similarity of individual Sparrowhawk pairs' diet was found (Mantel test, Z = 5630.30, correlation = 0.04, t = 3.79, P = 0.999; linear regression, $R^2_{adj} = 0.001$, $F_{1,1889} = 3.20$, P = 0.074).

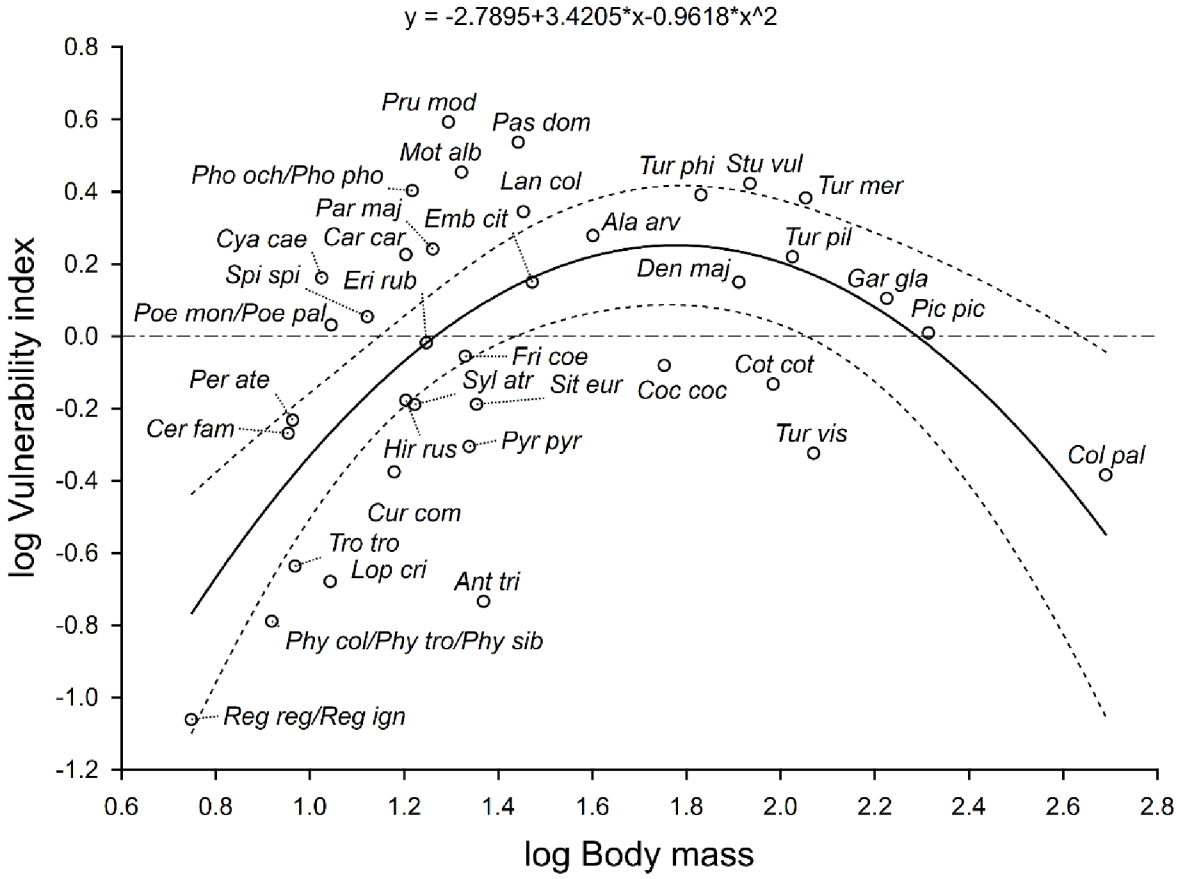

Figure 4. The effect of the prey species body mass on their vulnerability. The circles represent the prey species (n = 37 species). The solid line represents the regression line, the dotted lines represent 95% confidence interval. The dash-dotted line indicates proportional occurrence of prey species in the diet and food supply. The explanation of the species abbreviations: *Ala arv = Alauda arvensis, Ant tri = Anthus trivialis, Car car = Carduelis carduelis, Cer fam = Certhia familiaris, Coc coc = Coccothraustes coccothraustes, Col pal = Columba palumbus, Cot cot = Coturnix coturnix, Cur com = Curruca communis, Cya cae = Cyanistes caeruleus, Den maj = Dendrocopos major, Emb cit = Emberiza citrinella, Eri rub = Erithacus rubecula, Fri coe = Fringilla coelebs, Gar gla = Garrulus glandarius, Hir rus = Hirundo rustica, Lan col = Lanius collurio, Lop cri = Lophophanes cristatus, Mot alb = Motacilla alba, Par maj =*

Parus major, Pas dom = Passer domesticus, Per ate = Periparus ater, Pho och/Pho pho = Phoenicurus ochruros/Phoenicurus phoenicurus, Phy col/Phy tro/Phy sib = Phylloscopus collybita/Phylloscopus trochilus/Phylloscopus sibilatrix, Pic pic = Pica pica, Poe mon/Poe pal = Poecile montanus/Poecile palustris, Pru mod = Prunella modularis, Pyr pyr = Pyrrhula pyrrhula, Reg reg/Reg ign = Regulus regulus/Regulus ignicapilla, Sit eur = Sitta europaea, Spi spi = Spinus spinus, Stu vul = Sturnus vulgaris, Syl atr = Sylvia atricapilla, Tro tro = Troglodytes troglodytes, Tur mer = Turdus merula, Tur phi = Turdus philomelos, Tur pil = Turdus pilaris, Tur vis = Turdus viscivorus.

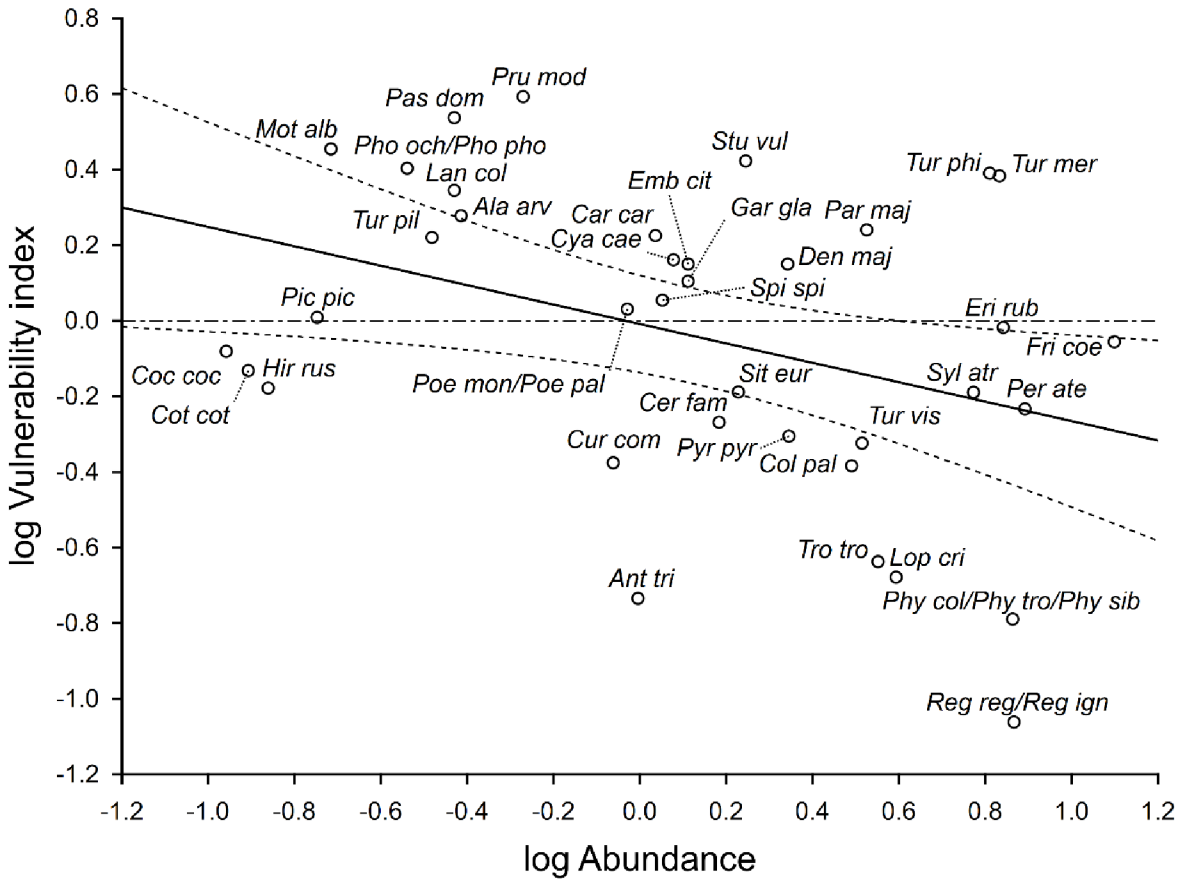

Figure 5. The effect of the prey species abundance in the food supply on their vulnerability. The circles represent the prey species (n = 37 species). The solid line represents the regression line, the dotted lines represent 95% confidence interval. The dash-dotted line indicates proportional occurrence of prey species in the diet and food supply. The explanation of the species abbreviations: *Ala arv = Alauda arvensis, Ant tri = Anthus trivialis, Car car = Carduelis carduelis, Cer fam = Certhia familiaris, Coc coc = Coccothraustes coccothraustes, Col pal = Columba palumbus, Cot cot = Coturnix coturnix, Cur com = Curruca communis,*

Cya cae = Cyanistes caeruleus, Den maj = Dendrocopos major, Emb cit = Emberiza citrinella, Eri rub = Erithacus rubecula, Fri coe = Fringilla coelebs, Gar gla = Garrulus glandarius, Hir rus = Hirundo rustica, Lan col = Lanius collurio, Lop cri = Lophophanes cristatus, Mot alb = Motacilla alba, Par maj = Parus major, Pas dom = Passer domesticus, Per ate = Periparus ater, Pho och/Pho pho = Phoenicurus ochruros/Phoenicurus phoenicurus, Phy col/Phy tro/Phy sib = Phylloscopus collybita/Phylloscopus trochilus/Phylloscopus sibilatrix, Pic pic = Pica pica, Poe mon/Poe pal = Poecile montanus/Poecile palustris, Pru mod = Prunella modularis, Pyr pyr = Pyrrhula pyrrhula, Reg reg/Reg ign = Regulus regulus/Regulus ignicapilla, Sit eur = Sitta europaea, Spi spi = Spinus spinus, Stu vul = Sturnus vulgaris, Syl atr = Sylvia atricapilla, Tro tro = Troglodytes troglodytes, Tur mer = Turdus merula, Tur phi = Turdus philomelos, Tur pil = Turdus pilaris, Tur vis = Turdus viscivorus.

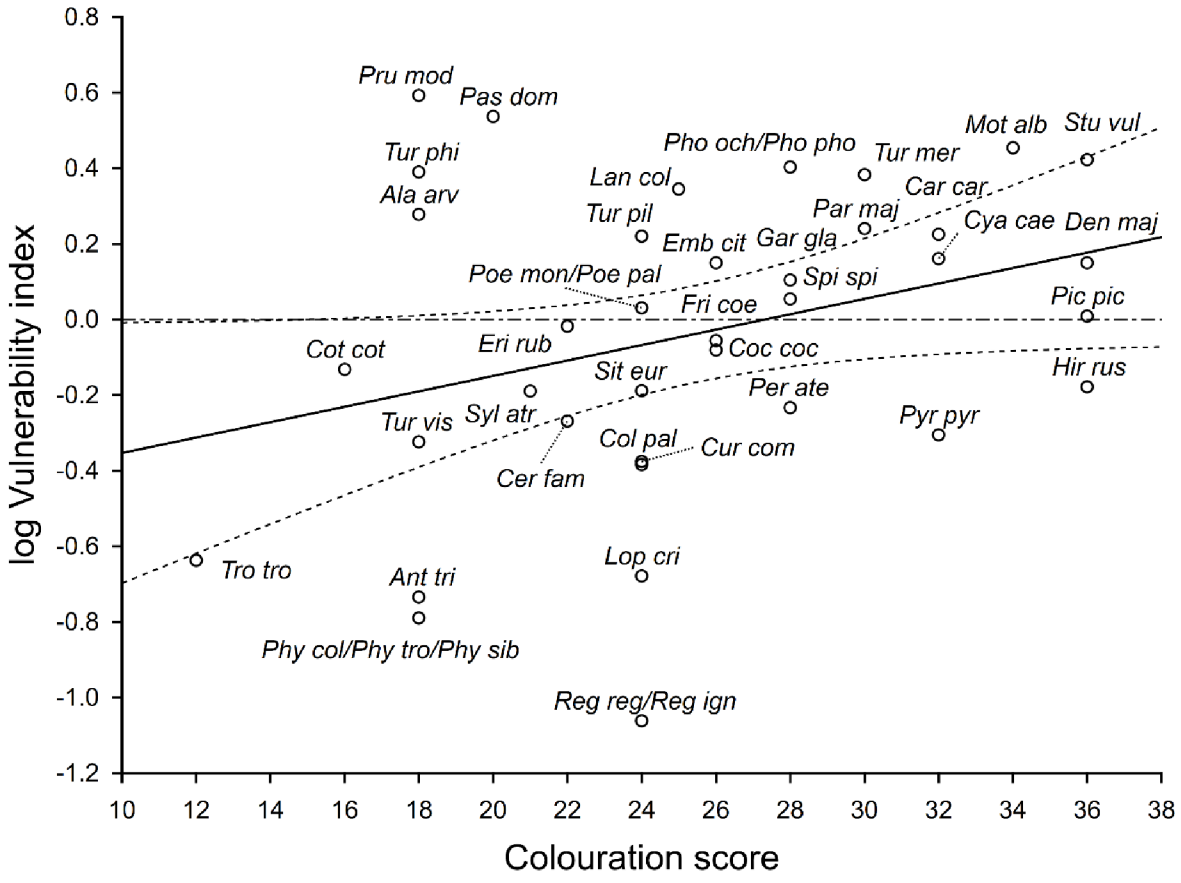

Figure 6. The effect of the prey species colouration on their vulnerability. Higher colouration scores indicate higher conspicuousness of colouration. The circles represent the prey species (n = 37 species). The solid line represents the regression line, the dotted lines represent 95% confidence interval. The dash-dotted line indicates proportional occurrence of prey species in

the diet and food supply. The explanation of the species abbreviations: *Ala arv = Alauda arvensis, Ant tri = Anthus trivialis, Car car = Carduelis carduelis, Cer fam = Certhia familiaris, Coc coc = Coccothraustes coccothraustes, Col pal = Columba palumbus, Cot cot = Coturnix coturnix, Cur com = Curruca communis, Cya cae = Cyanistes caeruleus, Den maj = Dendrocopos major, Emb cit = Emberiza citrinella, Eri rub = Erithacus rubecula, Fri coe = Fringilla coelebs, Gar gla = Garrulus glandarius, Hir rus = Hirundo rustica, Lan col = Lanius collurio, Lop cri = Lophophanes cristatus, Mot alb = Motacilla alba, Par maj = Parus major, Pas dom = Passer domesticus, Per ate = Periparus ater, Pho och/Pho pho = Phoenicurus ochruros/Phoenicurus phoenicurus, Phy col/Phy tro/Phy sib = Phylloscopus collybita/Phylloscopus trochilus/Phylloscopus sibilatrix, Pic pic = Pica pica, Poe mon/Poe pal = Poecile montanus/Poecile palustris, Pru mod = Prunella modularis, Pyr pyr = Pyrrhula pyrrhula, Reg reg/Reg ign = Regulus regulus/Regulus ignicapilla, Sit eur = Sitta europaea, Spi spi = Spinus spinus, Stu vul = Sturnus vulgaris, Syl atr = Sylvia atricapilla, Tro tro = Troglodytes troglodytes, Tur mer = Turdus merula, Tur phi = Turdus philomelos, Tur pil = Turdus pilaris, Tur vis = Turdus viscivorus.*

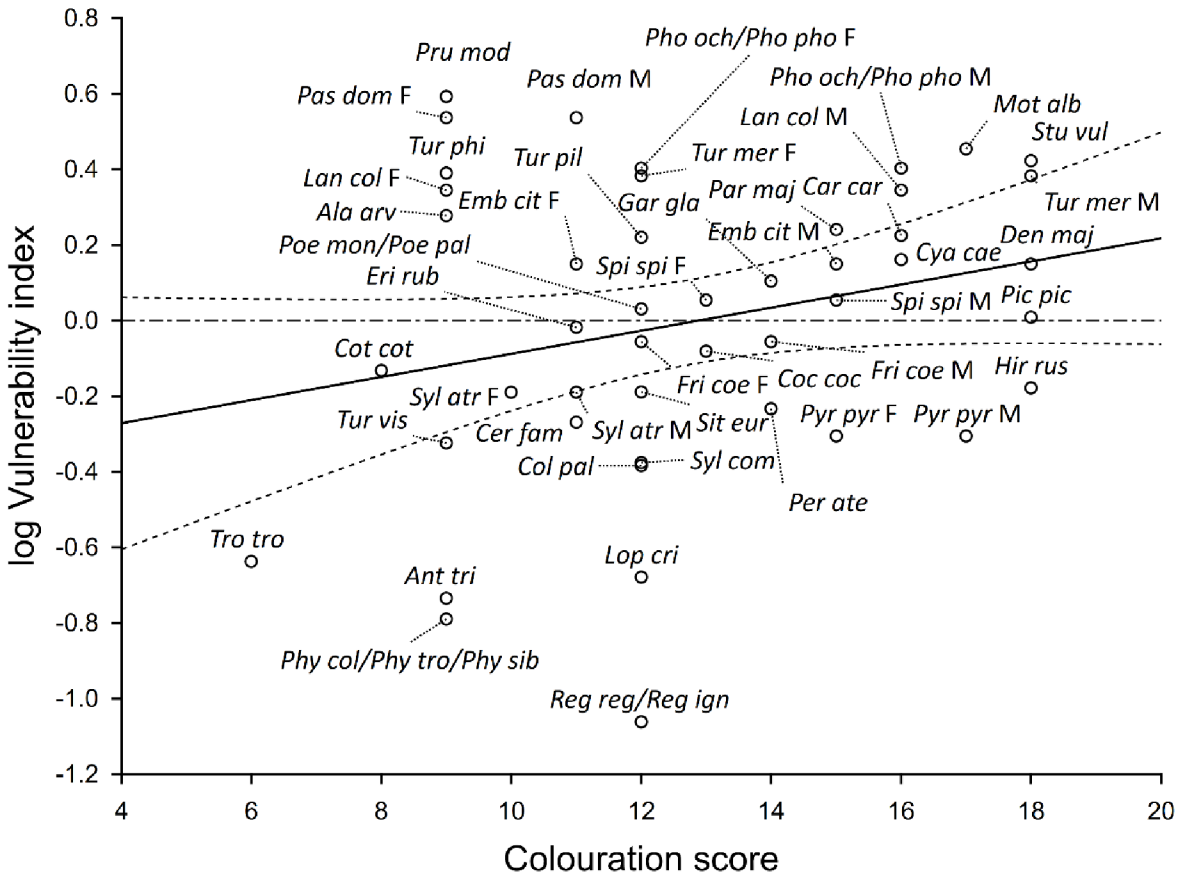

Figure 7. The effect of the prey species colouration on their vulnerability with the sexes of dimorphic species tested separately. Higher colouration scores indicate higher conspicuousness of colouration. The circles represent the prey species (n = 46 species). The solid line represents the regression line, the dotted lines represent 95% confidence interval. The dash-dotted line indicates proportional occurrence of prey species in the diet and food supply. The explanation of the species abbreviations: *Ala arv* = *Alauda arvensis, Ant tri* = *Anthus trivialis, Car car* = *Carduelis carduelis, Cer fam* = *Certhia familiaris, Coc coc* = *Coccothraustes coccothraustes, Col pal* = *Columba palumbus, Cot cot* = *Coturnix coturnix, Cur com* = *Curruca communis, Cya cae* = *Cyanistes caeruleus, Den maj* = *Dendrocopos major, Emb cit* F = *Emberiza citronella* female, *Emb cit* M = *Emberiza citronella* male, *Eri rub* = *Erithacus rubecula, Fri coe* F = *Fringilla coelebs* female, *Fri coe* M = *Fringilla coelebs* male, *Gar gla* = *Garrulus glandarius, Hir rus* = *Hirundo rustica, Lan col* F = *Lanius collurio* female, *Lan col* M = *Lanius collurio* male, *Lop cri* = *Lophophanes cristatus, Mot alb* = *Motacilla alba, Par maj* = *Parus major, Pas dom* F = *Passer domesticus* female, *Pas dom* M = *Passer domesticus* male, *Per ate* = *Periparus ater, Pho och/Pho pho* F = *Phoenicurus ochruros/Phoenicurus phoenicurus* female, *Pho och/Pho pho* M = *Phoenicurus*

ochruros/Phoenicurus phoenicurus male, *Phy col/Phy tro/Phy sib = Phylloscopus collybita/Phylloscopus trochilus/Phylloscopus sibilatrix, Pic pic = Pica pica, Poe mon/Poe pal = Poecile montanus/Poecile palustris, Pru mod = Prunella modularis, Pyr pyr* F = *Pyrrhula pyrrhula* female, *Pyr pyr* M = *Pyrrhula pyrrhula* male, *Reg reg/Reg ign = Regulus regulus/Regulus ignicapilla, Sit eur = Sitta europaea, Spi spi* F = *Spinus spinus* female, *Spi spi* M = *Spinus spinus* male, *Stu vul = Sturnus vulgaris, Syl atr* F = *Sylvia atricapilla* female, *Syl atr* M = *Sylvia atricapilla* male, *Tro tro = Troglodytes troglodytes, Tur mer* F = *Turdus merula* female, *Tur mer* M = *Turdus merula* male, *Tur phi = Turdus philomelos, Tur pil = Turdus pilaris, Tur vis = Turdus viscivorus.*

5 Discussion

The aims of this study were to assess the relationships between land cover, food supply and Sparrowhawk diet and the effect of several prey species characteristics on Sparrowhawk prey selection. The results revealed a significant link between land cover and the structure of food supply in the surroundings of the Sparrowhawk nests. Three assemblages of bird species associated with different types of land cover were found. The first assemblage was clearly linked to coniferous forests and consisted of not only species typically found in coniferous forests like the Coal Tit, Crested Tit, and Goldcrest but also species with wider ecological niches such as the Common Chaffinch and Eurasian Wren. The second assemblage was linked to mixed forests, broad-leaved forests, and artificial surfaces. The common feature of these land cover categories is the presence of broad-leaved trees resulting in similar bird species community structure. Therefore, this assemblage of bird species consisted of birds typically found together with broad-leaved trees such as the Willow Warbler, Garden Warbler, Spotted Flycatcher, and Blue Tit together with generalist birds (e.g. the Great Tit) and synanthropic birds (e.g. the Black Redstart). The third assemblage was linked to grassland and consisted of birds breeding within open habitats (e.g. the Eurasian Skylark, Tree Pipit, and Yellowhammer) and of birds often foraging in open habitats and breeding elsewhere (e.g. the Common Starling and European Goldfinch). This shows that different types of land cover (i.e. different habitats) are occupied by structurally different bird communities (e.g. Reif et al. 2008, Seymour & Dean 2010, Lemaître et al. 2012, Rocha et al. 2015, Casas et al. 2016, Sasaki et al. 2020). Therefore, the composition of land cover within the surroundings of Sparrowhawk nests may determine the structure of food supply available there. In consequence, the composition of land cover within Sparrowhawks' hunting areas may affect their diet composition.

The Sparrowhawk diet was comprised almost entirely of birds. This concurs to findings from other areas (Opdam 1978, Newton & Marquiss 1982, Newton 1986, Selås 1993, Petty et al. 1995, Rytkönen et al. 1998, Zawadska & Zawadski 2001, Bujoczek & Ciach 2009, Tomešek & Čermák 2009, Hernández 2018, Rodríguez et al. 2020). Only a few bird species represented a substantial part of the diet concerning both numbers (5 species formed 55.3% of prey items) and biomass (6 species formed 77.6% of prey biomass). This is also a common pattern found by other studies (Newton & Marquiss 1982, Newton 1986, Solonen 1997, Zawadska & Zawadski 2001, Hernández 2018). Interestingly, species such as the Common Blackbird, Song Thrush, Common Chaffinch, European Robin, Common Starling, Wood Pigeon and Great Tit form an important part of Sparrowhawk diet across different study areas

(Newton & Marquiss 1982, Newton 1986, Solonen 1997, Zawadska & Zawadski 2001, Bujoczek & Ciach 2009, Tomešek & Čermák 2009, Hernández 2018, Rodríguez et al. 2020). This suggests that some species may represent important Sparrowhawk prey despite the differences among various environments.

The PCA analysis of land cover within the surroundings (a buffer of 1 km radius) of the breeding territories showed that percentages of forests were negatively correlated with percentages of grassland, shrubs, and artificial surfaces. Percentages of artificial surfaces were positively correlated with shrubs and arable land. This may be caused by the frequent occurrence of shrubs on the outskirts of human settlements and by crop fields being usually located near them. Percentages of arable land seemed to be independent of forests and grasslands. This is a rather unexpected result possibly attributable to the low occurrence of arable land within the study area.

Two land cover categories had significant effect on the Sparrowhawk diet composition. Percentages of some forest species (e.g. the Common Blackbird, Song Thrush, Coal Tit, and European Pied Flycatcher) in the diet were positively correlated with percentages of forests within the surroundings of the breeding territories. Percentages of some typically synanthropic species (e.g. the Eurasian Collared Dove and Common Linnet) in the diet were positively correlated with percentages of artificial surfaces around the breeding territories. Moreover, percentages of some grassland species (e.g. the Eurasian Skylark and Yellowhammer) in the diet were negatively correlated with percentages of forests around the breeding territories. This may reflect the negative correlation between forests and grassland in the surroundings of the territories although the effect of grassland on diet composition was not significant. However, percentages of some synanthropic species (e.g. the House Sparrow and Black Redstart/Common Redstart) in the diet seemed to be independent of the percentages of artificial surfaces around the territories. Similarly, percentages of some species usually occurring in forests (e.g. the Eurasian Jay and Wood Pigeon) in the diet were positively correlated with percentages of artificial surfaces around the territories. These discrepancies might have resulted from the crude estimation of the Sparrowhawks' hunting areas (a buffer of 1 km radius) which might have included some areas where the Sparrowhawks did not hunt and omitted areas where they actually hunted. Nevertheless, this result supports the hypothesis about the effect of land cover on Sparrowhawk diet composition. Although more accurate data on real Sparrowhawks' hunting areas would be necessary to achieve better understanding of this effect. Nonetheless, Sparrowhawk diet composition reflecting the composition of habitats

close to their breeding sites has also been found by other studies (Newton & Marquiss 1982, Newton 1986, Rodríguez et al. 2020).

The Sparrowhawks did not hunt individual prey species proportionally to their occurrence in the food supply. Some species were preferred more than other species. The most preferred species were the Common Starling, Dunnock, European Goldfinch, Song Thrush, and Common Blackbird, whilst the least preferred species were the Goldcrest/Common Firecrest, Crested Tit, Common Chiffchaff/Willow Warbler/Wood Warbler, Eurasian Wren, and Wood Pigeon. The Common Starling, Song Thrush, and Common Blackbird have also been found vulnerable to Sparrowhawk predation by other studies (Selås 1993, Zawadska & Zawadski 2001). Some of the least preferred species, namely the Goldcrest, Willow Warbler, Common Chiffchaff, Crested Tit, and Eurasian Wren, have also been reported to be overlooked by Sparrowhawks within other study areas (Opdam 1978, Selås 1993, Götmark & Post 1996, Solonen 1997).

One reason possibly affecting Sparrowhawks' preference for some species may be based on prey species' behaviour. Behaviour of individual species may affect their detectability by hunting Sparrowhawks. For example, species often foraging in open areas (e.g. the Common Starling) may be more easily detected compared to species foraging in the undergrowth or foliage (e.g. the Eurasian Wren or Goldcrest respectively, Opdam 1978, Newton 1986, Götmark & Post 1996, Rytkönen et al. 1998). However, even some species usually living in bushes and undergrowth (e.g. the Eurasian Blackcap and European Robin) may be Sparrowhawks' preferred prey (Selås 1993). In this study, one behaviourally inconspicuous species (the Dunnock) was preferred Sparrowhawk prey. Behaviourally inconspicuous species foraging on the ground or nearby in undergrowth may be more difficult to detect, but they may be easier to ambush by a typical Sparrowhawk surprise attack (Newton 1986) due to the limited view of their surroundings compared to species in open areas (Selås 1993). However, this result may also be biased by inaccuracies in the data resulting from limitations in estimating individual prey species occurrence in the food supply and diet (see further text below). Moreover, other prey species characteristics such as body mass, abundance and plumage colouration may also affect their vulnerability to Sparrowhawk predation.

Prey species body mass significantly affected their vulnerability. The Sparrowhawks preyed upon birds within the wide body mass range of about 5.6 – 490 g, but they tended to prefer prey within the range of body mass of approximately 15 – 200 g. Many species within the preferred range occurred in the diet more than expected from their occurrence in the food supply. Sparrowhawks usually tend to prefer prey species within a specific body mass range

resulting in low occurrence of very small and very large species in their diet compared to food supply (Selås 1993, Götmark & Post 1996, Solonen 1997, Zawadska & Zawadski 2001, Bujoczek & Ciach 2009, Rodríguez et al. 2020). Therefore, prey within a specific body mass range (excluding too small and too large species) may be optimal for Sparrowhawks to hunt. Hunting must provide more energy compared to its costs. Since not every hunting attempt is successful, the energy costs include not only successful attempts but also unsuccessful ones. Therefore, hunting relatively large species may be necessary to compensate for the energy lost during unsuccessful hunting (Opdam 1978, Rytkönen et al. 1998, Bujoczek & Ciach 2009). Moreover, smaller birds are more manoeuvrable than larger ones. Therefore, small species not only provide less energy but are also more difficult to catch (Götmark & Post 1996, Rytkönen et al. 1998). However, large species may provide plenty of food and may be easier to catch, but with their increasing size they become more difficult for Sparrowhawks to subdue and kill. Therefore, hunting large species increases the risk of injury (Newton & Marquiss 1982). Moreover, very large species (e.g. the Wood Pigeon) may be difficult to carry to nests (Newton & Marquiss 1982). However, Rytkönen et al. (1998) found increasing prey vulnerability with its increasing size, and even the largest species (the Hazel Grouse *Tetrastes bonasia* with mean body mass of 429 g) was overrepresented in the Sparrowhawk diet compared to the food supply. This suggests that different Sparrowhawk populations may prefer prey within slightly different body mass ranges.

Increasing prey species abundance in the food supply decreased their vulnerability to Sparrowhawk predation. This is an unexpected result since increasing prey abundance increases the probability of encounters with Sparrowhawks (Petty et al. 1995). However, similar effect of prey species abundance on their vulnerability was also found by other studies (Götmark & Post 1996, Rytkönen et al. 1998). One possible explanation of this effect may be that less abundant species may be more vulnerable since Sparrowhawks tend to rely on surprise attacks during hunting, and less abundant species may be easier caught by surprise compared to abundant ones. Therefore, increased chance for ambushing less common prey species may be more important for Sparrowhawks compared to more frequent encountering with common prey species (Götmark & Post 1996, Rytkönen et al. 1998). Moreover, common prey species probably evolved better adaptations against Sparrowhawk attacks (Götmark & Post 1996, Rytkönen et al. 1998). However, results suggesting this effect may be biased by the accuracy of the used dataset. The data on food supply may be biased not only by differences in detectability of individual species (Riegert 2022), but also by the lack of knowledge of actual Sparrowhawks' hunting areas involved in the studies (e.g. Götmark & Post 1996,

Rytkönen et al. 1998, this study). Therefore, a certain level of inaccuracy leading to underrepresentation of some species is almost inevitable in food supply datasets. Moreover, since the data on Sparrowhawk diet are usually limited in volume, some prey species may be represented by higher proportions in the diet data sample than they are in the whole diet. Therefore, some species may be underrepresented in food supply data and simultaneously overrepresented in diet composition data. For example, some species found in the diet were not even recorded in the food supply in this study probably because of the before mentioned limitations of food supply data collection. This may result in inaccurate representations of prey species vulnerability, such as the vulnerability index, with higher values particularly in species with low abundance in food supply.

Increasing conspicuousness of prey species plumage colouration increased their vulnerability to Sparrowhawk predation. However, when the sexes of dimorphic species were tested separately, the statistical significance of the effect of plumage colouration on prey species vulnerability decreased. Plumage colouration affecting prey species vulnerability was also found by Rytkönen et al. (1998). Conspicuous plumage colouration may be more easily noticed by hunting Sparrowhawks so it may increase the frequency of attacks on conspicuous prey (Ruiz-Rodríguez et al. 2013). Even though this result supports the hypothesis about the effect of plumage colouration on prey species vulnerability, it may be biased by the assessment of plumage colouration and by the inability to calculate the vulnerability indices for the sexes of dimorphic species separately due to the frequently undistinguishable sex of the prey items from dimorphic prey species. Although human vision is likely capable of detection of a substantial part of bird plumage colouration variability within the visible spectrum (Bergeron & Fuller 2018), and raptors have low ultraviolet light transmittance (Lind et al. 2013, Lind et al. 2014), they may still perceive plumage colouration somewhat differently because of their tetrachromatic colour vision (Mitkus et al. 2018). Moreover, plumage conspicuousness also depends on the background provided by different habitats where individual species may occur. Thus, some species with seemingly conspicuous plumage may be somewhat cryptic within certain habitats (Götmark & Unger 1994). Furthermore, other studies have found either no effect of conspicuousness on prey species vulnerability (although this study was done on the Common Kestrel *Falco tinnunculus*, Huhta et al. 1998) or increased vulnerability of inconspicuous species suggesting that some species' conspicuous plumage colouration may function as a sign of unprofitable prey (Götmark & Unger 1994). The contradictory evidence on the effect of plumage conspicuousness on prey species vulnerability suggests that prey

species plumage colouration may be less important for Sparrowhawk prey selection compared to other prey species characteristics (e.g. body mass).

No effect of geographical distance on similarity of individual Sparrowhawk pairs' diet was found. This is an unexpected result since increasing geographical distance between individual breeding areas may increase differences in habitat structure (i.e. land cover) and thus it may affect the structure of food supply. Moreover, individual Sparrowhawks may prefer to hunt certain prey species according to their unique hunting experience and technique (Newton 1986). However, the effect of the structure of food supply is probably more important (Newton 1986). Since the study area is relatively small with the different types of land cover (i.e. different habitats) relatively evenly spread throughout it, increasing geographical distance between individual areas may not increase differences in the structure of land cover. This may explain no effect of geographical distance on similarity of Sparrowhawk pairs' diet composition shown by the results.

6 Conclusions

The structure of food supply within the surroundings of the nests was determined by the structure of land cover. The Sparrowhawk diet consisted almost exclusively of birds. Many prey species were taken, but only a limited number of species formed a substantial part of the diet. The diet composition was affected by the land cover structure within the surroundings of Sparrowhawk nesting sites. Individual prey species were not hunted proportionally to their occurrence in the food supply. Therefore, some prey species were more preferred compared to others. All the examined prey species characteristics affected Sparrowhawk prey selection. Firstly, the Sparrowhawks tended to prefer prey species within the range of body mass of approximately 15 – 200 g. Secondly, the Sparrowhawks seemed to prefer prey species with lower abundance in the food supply. Finally, the Sparrowhawks appeared to prefer prey species with seemingly more conspicuous plumage colouration. However, each prey species possesses a combination of these and other characteristics, which may affect its attractivity for hunting Sparrowhawks leading to specific hunting preferences. Nevertheless, the results may involve a certain level of bias stemming from the limitations of the methods of estimating structure of food supply, Sparrowhawk diet composition, and prey species plumage colouration. In summary, this study suggests that Sparrowhawks specialize in hunting birds, but they can hunt a wide range of available species, some of which may be more preferred than others depending on their unique set of characteristics.

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8 Supplementary material

Table S1. The plumage colouration scores of the prey species. The species are ordered from the highest to the lowest plumage conspicuousness.

Species	Colouration score
Dendrocopos major	36
Pica pica	36
Sturnus vulgaris	36
Hirundo rustica	36
Motacilla alba	34
Cyanistes caeruleus	32
Carduelis carduelis	32
Pyrrhula pyrrhula	32
Turdus merula	30
Parus major	30
Periparus ater	28
Spinus spinus	28
Garrulus glandarius	28
Phoenicurus ochruros/Phoenicurus phoenicurus	28
Fringilla coelebs	26
Emberiza citrinella	26
Coccothraustes coccothraustes	26
Lanius collurio	25
Turdus pilaris	24
Poecile montanus/Poecile palustris	24
Lophophanes cristatus	24
Regulus regulus/Regulus ignicapilla	24
Sylvia communis	24
Sitta europaea	24
Columba palumbus	24
Erithacus rubecula	22
Certhia familiaris	22
Sylvia atricapilla	21
Passer domesticus	20
Turdus philomelos	18
Turdus viscivorus	18
Alauda arvensis	18
Anthus trivialis	18
Phylloscopus collybita/Phylloscopus trochilus/Phylloscopus sibilatrix	18
Prunella modularis	18
Coturnix coturnix	16
Troglodytes troglodytes	12

Table S2. The plumage colouration scores of the prey species with separated sexes of the dimorphic species. The species are ordered from the highest to the lowest plumage conspicuousness.

Species	Colouration score
Dendrocopos major	18
Hirundo rustica	18
Pica pica	18
Sturnus vulgaris	18
Turdus merula male	18
Motacilla alba	17
Pyrrhula pyrrhula male	17
Cyanistes caeruleus	16
Carduelis carduelis	16
Lanius collurio male	16
Phoenicurus ochruros/Phoenicurus phoenicurus male	16
Parus major	15
Spinus spinus male	15
Emberiza citrinella male	15
Pyrrhula pyrrhula female	15
Periparus ater	14
Fringilla coelebs male	14
Garrulus glandarius	14
Spinus spinus female	13
Coccothraustes coccothraustes	13
Turdus merula female	12
Turdus pilaris	12
Poecile montanus/Poecile palustris	12
Lophophanes cristatus	12
Fringilla coelebs female	12
Regulus regulus/Regulus ignicapilla	12
Sylvia communis	12
Sitta europaea	12
Columba palumbus	12
Phoenicurus ochruros/Phoenicurus phoenicurus female	12
Emberiza citrinella female	11
Erithacus rubecula	11
Sylvia atricapilla male	11
Certhia familiaris	11
Passer domesticus male	11
Sylvia atricapilla female	10
Turdus philomelos	9
Turdus viscivorus	9
Alauda arvensis	9
Anthus trivialis	9
Phylloscopus collybita/Phylloscopus trochilus/Phylloscopus sibilatrix	9
Prunella modularis	9
Lanius collurio female	9
Passer domesticus female	9
Coturnix coturnix	8
Troglodytes troglodytes	6

Table S3. The percentages of prey items and biomass of individual prey species recorded in the diet. The bird species are ordered from the highest to the lowest percentage of prey items.

Species	Items (%)	Biomass (%)
Turdus merula	16.3	32.1
Turdus philomelos	15.7	18.6
Fringilla coelebs	10.9	4.1
Erithacus rubecula	6.6	2.0
Parus major	5.8	1.8
Sturnus vulgaris	4.6	6.9
Periparus ater	4.5	0.7
Sylvia atricapilla	3.8	1.1
Dendrocopos major	3.1	4.4
Prunella modularis	2.1	0.7
Carduelis carduelis	1.8	0.5
Emberiza citrinella	1.8	0.9
Cyanistes caeruleus	1.7	0.3
Garrulus glandarius	1.6	4.8
Turdus viscivorus	1.5	3.2
Columba palumbus	1.3	10.8
Passer domesticus	1.3	0.6
Spinus spinus	1.3	0.3
Phylloscopus collybita/Phylloscopus trochilus/Phylloscopus sibilatrix	1.2	0.2
Pyrrhula pyrrhula	1.1	0.4
Sitta europaea	1.1	0.4
Poecile montanus/Poecile palustris	1.0	0.2
Certhia familiaris	0.8	0.1
Lanius collurio	0.8	0.4
Lophophanes cristatus	0.8	0.2
Troglodytes troglodytes	0.8	0.1
Alauda arvensis	0.7	0.5
Phoenicurus ochruros/Phoenicurus phoenicurus	0.7	0.2
Regulus regulus/Regulus ignicapilla	0.6	0.1
Motacilla alba	0.6	0.2
Turdus pilaris	0.6	1.0
Aegithalos caudatus	0.3	0.1
Curruca communis	0.3	0.1
Linaria cannabina	0.3	0.1
Anthus trivialis	0.2	0.1
Pica pica	0.2	0.1
Coturnix coturnix	0.1	0.2
Streptopelia decaocto	0.1	0.2
Coccothraustes coccothraustes	0.1	0.1
Acanthis cabaret	0.1	<0.1
Delichon urbicum	0.1	<0.1
Ficedula hypoleuca	0.1	<0.1
Hirundo rustica	0.1	<0.1
Chloris chloris	0.1	<0.1
Lullula arborea	0.1	<0.1
Motacilla cinerea	0.1	<0.1
Saxicola rubetra	0.1	<0.1
Saxicola rubicola	0.1	<0.1
Clethrionomys glareolus	0.5	0.2
Small mammals	0.5	0.2

Table S4. The ranking matrix from compositional analysis of Sparrowhawk hunting 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*	*Poe.mon/Poe.pal*	*Cya.cae*	*Lop.cri*	*Per.ate*	*Mot.alb*	*Fri.coe*	*Car.car*	*Spi.spi*	*Emb.cit*	*Reg.reg/Reg.ign*	*Eri.rub*	*Tro.tro*	*Syl.atr*	*Syl.com*
Tur.mer	0																		
Tur.phi	+	0																	
Tur.vis	---	---	0																
Tur.pil	-	-	+++	0															
Par.maj	---	---	+++	-	0														
Poe.mon/Poe.pal	---	---	+++	-	-	0													
Cya.cae	-	-	+++	+	+++	+++	0												
Lop.cri	---	---	---	---	---	---	---	0											
Per.ate	---	---	+	---	-	-	---	+++	0										
Mot.alb	-	-	+++	-	+	+	-	+++	+++	0									
Fri.coe	---	---	+++	-	+	+	-	+++	+++	-	0								
Car.car	+	+	+++	+	+++	+++	+	+++	+++	+	+	0							
Spi.spi	---	---	+++	-	+	+	-	+++	+++	-	-	-	0						
Emb.cit	---	---	+++	---	-	-	---	+++	+	---	-	---	-	0					
Reg.reg/Reg.ign	---	---	---	---	---	---	---	-	---	---	---	---	---	---	0				
Eri.rub	---	---	+	---	-	-	---	+++	+	---	-	---	-	-	+++	0			
Tro.tro	---	---	-	---	---	---	---	+	---	---	---	---	---	---	+++	---	0		
Syl.atr	---	---	+	---	---	---	---	+++	-	---	---	---	---	---	+++	-	+++	0	
Syl.com	---	---	+++	---	-	-	---	+++	+	---	-	---	-	-	+++	+	+++	+	0
Ala.arv	-	-	+++	-	+	+	-	+++	+++	-	+	-	+	+	+++	+++	+++	+++	+++
Ant.tri	---	---	+++	---	-	-	---	+++	+	---	---	---	-	-	+++	+	+++	+	-
Pyr.pyr	---	---	+	---	---	---	---	+++	-	---	---	---	---	---	+++	-	+	-	---
Den.maj	---	---	+++	-	-	+	-	+++	+	-	-	---	-	+	+++	+	+++	+++	+
Gar.gla	---	---	+	---	---	---	---	+++	-	---	---	---	---	---	+++	-	+++	+	-
Pic.pic	-	-	+++	-	+	+	-	+++	+++	-	+	-	+	+++	+++	+++	+++	+++	+++
Phy.col/Phy.tro/Phy.sib	---	---	---	---	---	---	---	+	---	---	---	---	---	---	+	---	-	---	---
Stu.vul	+	+	+++	+	+++	+++	+	+++	+++	+++	+++	+	+++	+++	+++	+++	+++	+++	+++
Coc.coc	-	-	+++	-	+	+	-	+++	+++	-	+	-	+	+++	+++	+++	+++	+++	+++
Sit.eur	---	---	+	---	-	-	---	+++	+	-	-	---	-	-	+++	+	+++	+	-
Col.pal	---	---	-	---	---	---	---	+	-	---	---	---	---	---	+++	---	+	-	---
Cer.fam	---	---	+	---	---	---	---	+++	-	---	---	---	---	---	+++	-	+++	+	-
Pru.mod	+	+	+++	+	+++	+++	+	+++	+++	+	+++	+	+	+++	+++	+++	+++	+++	+++
Cot.cot	-	---	+++	-	+	+	-	+++	+++	-	+	-	+	+++	+++	+++	+++	+++	+++
Lan.col	-	-	+++	-	+	+	-	+++	+++	+	+	-	+	+++	+++	+++	+++	+++	+++
Hir.rus	-	-	+++	-	+	+	-	+++	+++	+	+	-	+	+++	+++	+++	+++	+++	+++

Pho.och/Pho.pho	-	-	+++	-	+	+	-	+++	+++	-	+	-	+	+	+++	+++	+++	+++	+++
Pas.dom	-	-	+++	+	+	+++	-	+++	+++	+	+++	-	+	+++	+++	+++	+++	+++	+++

Table S4. Continued.

	Ala.arv	*Ant.tri*	*Pyr.pyr*	*Den.maj*	*Gar.gla*	*Pic.pic*	*Phy.col/Phy.tro/Phy.sib*	*Stu.vul*	*Coc.coc*	*Sit.eur*	*Col.pal*	*Cer.fam*	*Pru.mod*	*Cot.cot*	*Lan.col*	*Hir.rus*	*Pho.och/Pho.pho*	*Pas.dom*
Ala.arv	0																	
Ant.tri	---	0																
Pyr.pyr	---	-	0															
Den.maj	-	+	+++	0														
Gar.gla	---	-	+	---	0													
Pic.pic	+	+++	+++	+	+++	0												
Phy.col/Phy.tro/Phy.sib	---	---	---	---	---	---	0											
Stu.vul	+++	+++	+++	+++	+++	+++	+++	0										
Coc.coc	+	+++	+++	+	+++	-	+++	---	0									
Sit.eur	---	+	+	-	+	---	+++	---	---	0								
Col.pal	---	---	-	---	-	---	+	---	---	---	0							
Cer.fam	---	-	+	-	-	---	+++	---	---	-	+	0						
Pru.mod	+	+++	+++	+++	+++	+	+++	-	+	+++	+++	+++	0					
Cot.cot	+	+++	+++	+	+++	-	+++	---	-	+++	+++	+++	-	0				
Lan.col	+	+++	+++	+	+++	+	+++	-	+	+++	+++	+++	-	+	0			
Hir.rus	+	+++	+++	+	+++	+	+++	---	+	+++	+++	+++	-	+	-	0		
Pho.och/Pho.pho	+	+++	+++	+	+++	-	+++	---	-	+++	+++	+++	-	+	-	-	0	
Pas.dom	+	+++	+++	+++	+++	+	+++	-	+	+++	+++	+++	-	+	+	+	+	0

The explanation of species abbreviations used in Table S4: *Ala.arv = Alauda arvensis, Ant.tri = Anthus trivialis, Car.car = Carduelis carduelis, Cer.fam = Certhia familiaris, Coc.coc = Coccothraustes coccothraustes, Col.pal = Columba palumbus, Cot.cot = Coturnix coturnix, Cur.com = Curruca communis, Cya.cae = Cyanistes caeruleus, Den.maj = Dendrocopos major, Emb.cit = Emberiza citrinella, Eri.rub = Erithacus rubecula,*

Fri.coe = Fringilla coelebs, Gar.gla = Garrulus glandarius, Hir.rus = Hirundo rustica, Lan.col = Lanius collurio, Lop.cri = Lophophanes cristatus, Mot.alb = Motacilla alba, Par.maj = Parus major, Pas.dom = Passer domesticus, Per.ate = Periparus ater, Pho.och/Pho.pho = Phoenicurus ochruros/Phoenicurus phoenicurus, Phy.col/Phy.tro/Phy.sib = Phylloscopus collybita/Phylloscopus trochilus/Phylloscopus sibilatrix, Pic.pic = Pica pica, Poe.mon/Poe.pal = Poecile montanus/Poecile palustris, Pru.mod = Prunella modularis, Pyr.pyr = Pyrrhula pyrrhula, Reg.reg/Reg.ign = Regulus regulus/Regulus ignicapilla, Sit.eur = Sitta europaea, Spi.spi = Spinus spinus, Stu.vul = Sturnus vulgaris, Syl.atr = Sylvia atricapilla, Tro.tro = Troglodytes troglodytes, Tur.mer = Turdus merula, Tur.phi = Turdus philomelos, Tur.pil = Turdus pilaris, Tur.vis = Turdus viscivorus.