



Changes in vegetation and post-breeding habitat-related distribution of passerines in western Hungary

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Received: 6 February 2026 / Accepted: 7 September 2026
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Abstract

Studying habitat selection in birds provides important insights into how different habitat types influence survival. However, knowledge of the habitat-related distribution of birds during the post-breeding period and its relationship with vegetation structure remains incomplete. This study was conducted at an approximately 15 ha resting, feeding and shelter site in western Hungary during the post-breeding seasons between 2001 and 2024. Fifty commonly occurring passerine species were selected to examine their distribution across habitat types and how this distribution changes in response to vegetation dynamics. In total, 129,952 individuals representing 50 species were captured and ringed. Willow stands and other woody vegetation were delineated as polygons on georeferenced orthophotos, and their spatial extent was quantified for each study year. Based on capture rates, bird species were unevenly distributed among the four habitat types. Canonical Correspondence Analysis (CCA) indicated that vegetation physiognomy and coverage were the primary factors shaping the habitat-related distribution of birds. Habitat–period model analyses revealed temporal changes in habitat associations, which were consistent with the long-term development of vegetation structure at the study site. Species associated with dense shrub vegetation (e.g. Eurasian bullfinch *Pyrrhula pyrrhula*, common firecrest *Regulus ignicapilla*) or forest habitats (e.g. wood warbler *Phylloscopus sibilatrix*, European pied flycatcher *Ficedula hypoleuca*) showed increasing relative capture probabilities in swamp habitat over the study period. In contrast, species typically associated with open habitats (e.g. red-backed shrike *Lanius collurio*, whinchat *Saxicola rubetra*) showed decreasing associations with swamp habitat. These results indicate temporal shifts in habitat use among passerine species during the post-breeding period and highlight the importance of maintaining habitat heterogeneity in post-breeding areas.

Keywords Habitat-related distribution · Habitat types · Songbird species · Hungary

Introduction

Understanding how birds select and use habitats is a central focus of avian ecology and conservation biology. For bird species, habitat use and selection are further complicated by seasonal shifts in habitat associations, which reflect birds'

responses to spatial and temporal variation in environmental conditions, as well as changes in ecological requirements across the annual cycle (Dingle 1996; Deppe and Rotenberry 2008).

Habitat selection in birds constitutes an adaptive behavioral strategy during the post-breeding period, shaping patterns of resource utilization and spatial distribution (Chernetsov 2002, 2006). Despite their close relationship, habitat selection and spatial behavior represent distinct ecological phenomena with different implications for understanding avian movements and habitat use (Chernetsov 2012). Investigating the distribution of birds across habitat types and identifying habitat-use patterns are fundamental for informing effective conservation strategies and advancing our understanding of avian ecology (Caughley and Sinclair 1994; Krebs 1994; Johnson and Sherry 2001). Movement patterns of birds using stopover sites for resting and foraging are highly variable: some individuals

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establish small home ranges and exhibit limited movements within a given habitat, whereas others cover extensive areas within stopover sites during the post-breeding dispersal period and migration (Aborn and Moore 1997; Titov 1999; Chernetsov et al. 2004; Chernetsov and Mukhin 2006).

Increasing loss and fragmentation of post-breeding habitats due to human activities and global climate change has altered the population dynamics and migratory behavior of many bird species (Gaston et al. 2003; Chen and Wang 2024). Habitat fragmentation is one of the most significant threats to both breeding, dispersing and migratory populations, as habitat quality directly affects survival, stopover duration, fat accumulation, and migration speed (Chape et al. 2005; Luo et al. 2024). Although fragmentation can influence the behavior and habitat-specific distribution of birds, most passerines use post-breeding habitats in a non-random manner, even if their habitat preferences during migration are broader than during the breeding season. Reductions in habitat size caused by fragmentation can have particularly negative consequences for birds during the post-breeding period (Hasui et al. 2024; Belcik et al. 2020).

Birds' choice of habitat types is particularly important, as conservation of migratory species often relies on management of stopover habitats (Morrison et al. 1998). Dispersing and migratory birds move among habitats more frequently than residents and are common subjects of stopover studies (Cody 1985). Although most research on migratory bird habitat selection has focused on breeding populations, habitat selection during post-breeding dispersal period and migration may be simpler, as birds are not constrained by nesting activities (Hutto 1985).

The habitat-related distribution of dispersing and migratory birds can be influenced by multiple factors, including vegetation structure and plant species composition (Preisner and Csörgő 2008), prey availability (Levey and Stiles 1992; Sherry and Holmes 1996), predation risk (Rappole et al. 1989), habitat preferences from the breeding period (Morse 1971; Hutto 1980), evolutionary responses to paleoecological conditions (Johnson and Sherry 2001), and competition and population abundance (Greenberg 1986; Leisler 1992; Marra 2000). Density of intra- and interspecific competitors may affect habitat quality and, consequently, patterns of habitat selection at post-breeding sites (Moore and Yong 1991). Vegetation architecture and other habitat characteristics may change over time due to plant succession, potentially altering the habitat-related distribution of birds (Suthers et al. 2000).

In this study, we focused on fifty commonly occurring passerine species that are abundant during the post-breeding period and rely on the study area as a resting, feeding and shelter site (Gyurácz et al. 2017, 2023). We examined (1) how habitat selection differs among species during the post-breeding period, and (2) how vegetation structure and bird habitat-related distribution changed between 2001 and

2024. Our results provide critical insights into post-breeding habitat preferences and habitat-related distribution patterns, offering guidance for conservation and management of roosting, feeding and sheltering habitats.

Material and methods

Study site

The study was carried out at the Tömörd Bird Ringing Station in western Hungary (47°21'N 16°40'E), 15 km from Szombathely. The study area covers approximately 15 ha and encompasses four distinct natural, semi-natural habitat types, each with different vegetation architectures and plant species compositions (Fig. 1). (1) Forest (7 ha, 4 mist nets): broadleaf trees and shrubs show compact, dense edge vegetation, forming an ecotone community with turkey oak *Quercus cerris* Linnaeus, 1753 as the characteristic plant. Forest management is taking place. (2) Bush (4 ha, 7 mist nets): the shrub and herbaceous layer are made up of compact, dense vegetation, with intermittent small grass patches. There are a lot of fruits in the bush. The characteristic plants are the blackthorn *Prunus spinosa* Linnaeus, 1753 and hawthorn *Crataegus monogyna* Jacquin, 1775. (3) Grassland with shrubs (5 ha, 11 mist nets): this represents a transition between the wet habitats of the swamp and the steppe communities that used to cover the croplands around the marsh. The grassland is dominated by *Poa* spp. Linnaeus, 1753 with more patches of blackthorn, hawthorn and dwarf elder *Sambucus ebulus* Linnaeus, 1753. There is no cultivation on grassland. (4) Swamp (6.4 ha, 6 mist nets): a small permanent and isolated wetland (Lake Tömörd). It was dried out in 2001, but from 2002, rainwater began accumulate there again and marsh vegetation reappeared in 2003. The characteristic plants are great manna grass *Glyceria maxima* Holmb, 1919, willow *Salix cinerea* Linnaeus, 1753, and reedmace *Typha latifolia* Linnaeus, 1753. The study area is bordered by extensive ploughland to the south and west.

Data collection

Over the past 20 years, aerial imagery of Lake Tömörd and its surrounding vegetation was acquired in 2003, 2009, 2013, 2018, 2022, and 2024, at irregular intervals ranging from two to six years. Initially, image acquisition was performed using a custom-built radio-controlled (RC) model aircraft, and in later years by means of an unmanned aerial system (UAS). In addition, Google Earth imagery was used whenever suitable imagery was available for a given year. Birds were captured and ringed from 2001 to 2024 during the post-fledging period (dispersion and migration) from 1 August to 5 November. We used 28 numbered Ecotone

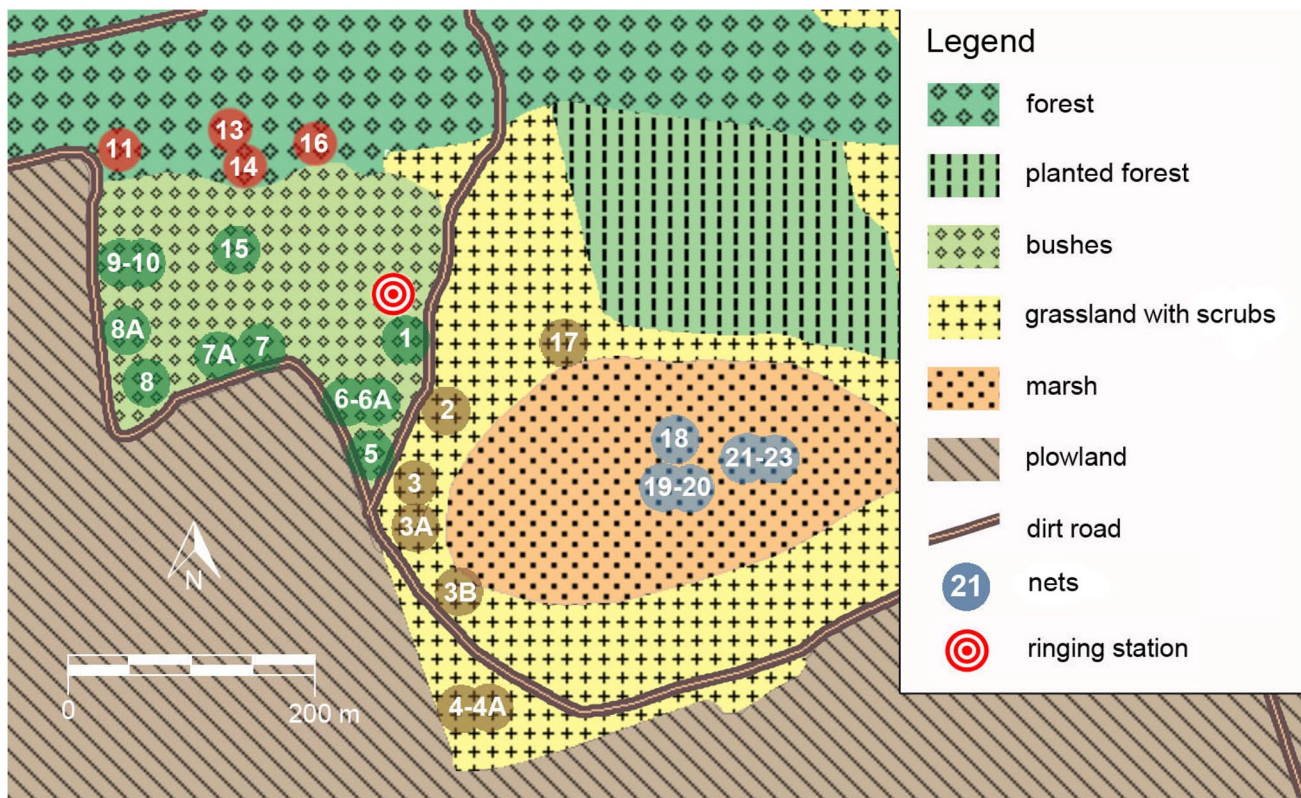


Fig. 1 Habitat map of the study area with the sites of mist nets

mist nets (12 m long and 2.5 m high with 5 shelves and a mesh size of 16 mm) for trapping. Birds were captured from dawn to dusk, except on rainy and stormy days when the nets were closed. All birds were ringed and aged according to Svensson (1992). In total, 129,952 individuals of 50 species were ringed. We caught most individuals from European robins *Erithacus rubecula* (Linnaeus, 1758) (20,029 indiv.), and the fewest from meadow pipits *Anthus pratensis* (Linnaeus, 1758) (101 indiv.) and barred warblers *Curruca nisoria* (Bechstein, 1792) (101 indiv.).

Data analyses

The willow–shrub–thicket (woody) vegetation was delineated as polygons on georeferenced orthophotos for each survey year, and the area of each polygon was quantified using Google Earth. Polygon areas were expressed as percentages of the reference area (lake basin and surrounding areas; Figs. 2 and 3) to visualize temporal changes in woody vegetation cover. Temporal trends in the spatial extent of woody vegetation were analyzed using a general linear model (GLM), with woody vegetation extent as the response variable and survey year as a continuous predictor variable.

There was different number of nets at different habitats, thus captures were standardized per net = mean (captures/number of mist nets in each habitat type) to ensure comparability among habitats. The means were the actual input data for the analyses. Canonical correspondence analysis (CCA) was used to relate species composition to environmental variation and identify habitat types influencing habitat selection of 50 passerine species during autumn. To complement the CCA, redundancy analysis (RDA) was also applied to assess linear relationships between species abundances and environmental variables (Legendre and Gallagher 2001). The input data for both the CCA and RDA consisted of the net-standardized relative capture rates of each species. No data transformation was applied prior to the analyses. Habitat type was used as the explanatory variable, and the statistical significance of the ordination models was assessed using a Monte Carlo permutation test with 999 permutations. Together, these multivariate approaches allowed us to evaluate how vegetation structure and habitat types shaped the habitat-related distribution of birds at the post-breeding site. To assess temporal changes in habitat use, multinomial logistic regression (MLR) models were fitted separately for each species. Habitat type at the capture site was used as the multinomial response variable, with bush habitat

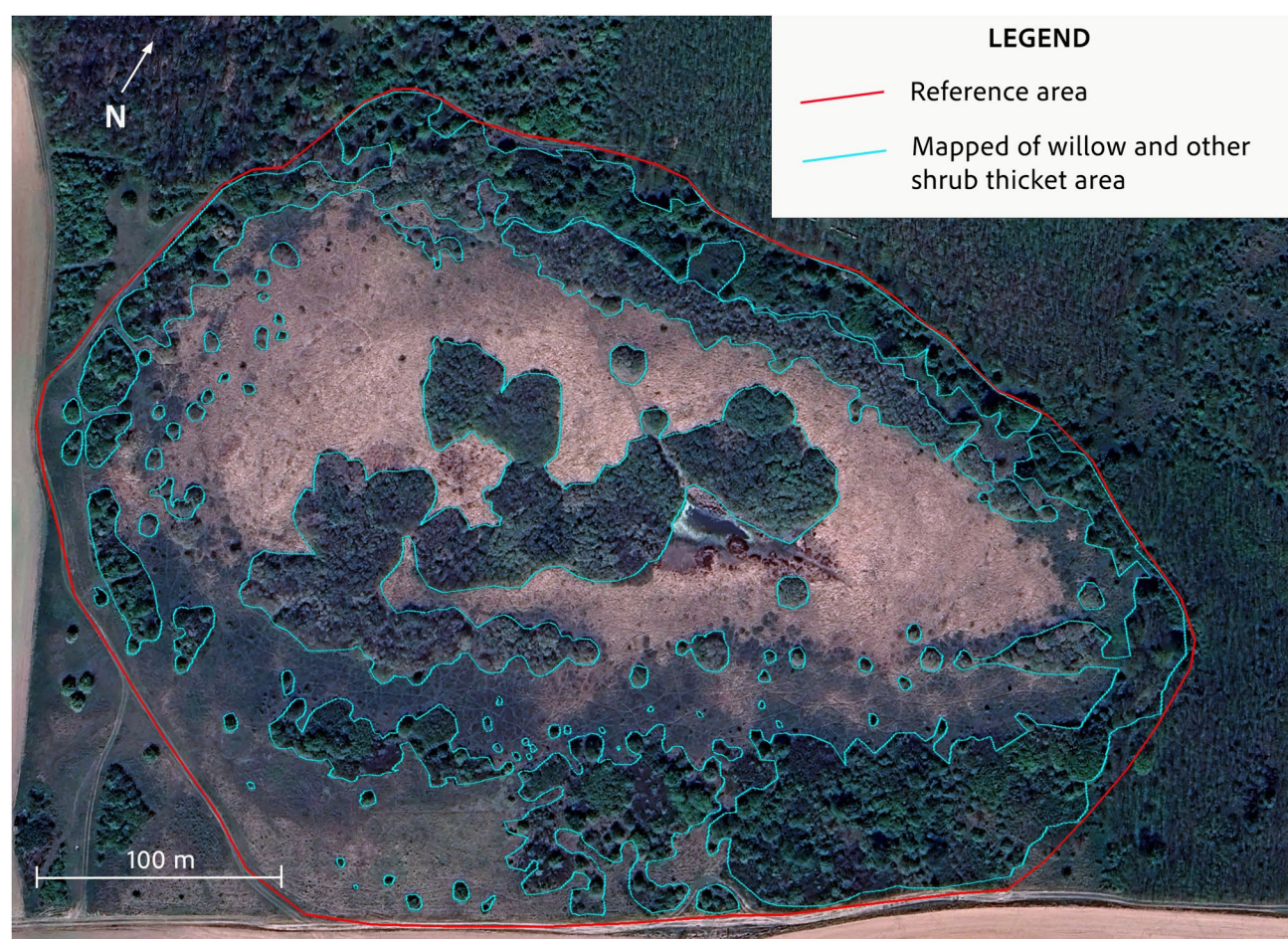


Fig. 2 Polygon-based delineation of willow and other shrub thicket areas on the 2022 aerial imagery

as the reference category. The predictor variable was the temporal period of the study, coded as an ordinal continuous variable (period 1–3: 2001–2008, 2009–2016, 2017–2024), representing successive stages of the study period. This coding allowed us to test for linear temporal trends in habitat use. Odds ratios indicate the change in the relative probability of capture in a given habitat category relative to bush habitat with increasing study period. Only transient (non-recaptured) individuals were included to avoid pseudo-replication, and age groups were pooled because species-specific habitat selection shows minimal change with age (Bairlein 1983). MLR allowed us to identify whether the probability of selecting particular habitats varied systematically across the post-breeding period. In our dataset, 47 of the 50 species are migratory, while only three are resident. Consequently, migratory status (resident vs. migratory) is highly unbalanced and was not considered as an explanatory variable in the analyses. The Past 4.03 and R 5.2.3 computer programs were used for the statistical analysis (Hammer et al. 2001; Hlavac 2022).

Results

Ordination of bird-habitat data by canonical correspondence analysis

Based on capture rates, the captured individuals of species were not evenly distributed among the four habitats (Fig. 4). Figure 5 shows the ordination diagram of the bird species captured during post-breeding period between 2001 and 2024. We interpreted the first axis (eigenvalue = 0.331, 62.77%, $p = 0.001$) as a successional gradient from swamp to forest, and the second axis (eigenvalue = 0.158, 29.93%, $p < 0.001$) a closeness-openness gradient. Positions of the bird species reveal the associations between individual passerines and habitat types. CCA placed climax specialist for the forest (e.g., European pied flycatcher *Ficedula hypoleuca* (Pallas, 1764), Eurasian nuthatch *Sitta europaea* (Linnaeus, 1758), Eurasian treecreeper *Certhia familiaris* Linnaeus, 1758) under left corner of the diagram. Similar to forest specialist species, species that prefer shrubs (e.g., spotted flycatcher *Muscicapa striata* (Pallas, 1764), common



Fig. 3 Extent of willow–shrub thicket habitats delineated in 2022, overlaid on the 2003 aerial image (showing vegetation changes over the 20-year period)

firecrest *Regulus ignicapilla* (Temminck, 1820) and short-toed treecreeper *C. brachydactyla* C. L. Brehm, 1820) are also placed to under left quarter of the diagram, but closer to the upper second axis. In the inner parts of the chart there are habitat generalist (e.g., common chiffchaff *Phylloscopus collybita* (Vielliot, 1817), Eurasian wren *Troglodytes troglodytes* (Linnaeus, 1758), European robin). Some wetland specialist species (meadow pipit, sedge warbler *Acrocephalus schoenobaenus* (Linnaeus, 1758), Eurasian reed warbler *A. scirpaceus* (Hermann, 1804)) and the barn swallow *Hirundo rustica* Linnaeus, 1758, common house martin *Delichon urbicum* (Linnaeus, 1758) are placed to under right corner of the diagram. Barred warbler, red-backed shrike *Lanius collurio* Linnaeus, 1758 and whinchat *Saxicola rubetra* (Linnaeus, 1758) are positioned to the upper second axis, showing a close association with openness. In CCA habitat types are presented by green lines (vectors), where angle with any of the axis show close relation between the habitats and the axis. The length of the lines represents the relative importance of the habitat types

in birds' habitat selection. The RDA also confirmed these bird species-habitat relationships ($R^2 = 0.732$, $F = 64.28$, $p = 0.001$).

Change of vegetation and bird habitat-related distribution by habitat-period model

The structure and spatial extent of forest vegetation did not change significantly, while advanced vegetation succession was characteristic of grassland with shrubs and swamp habitats during the study period. There were few willow shrubs and other bushes in the grassland with shrubs and marsh in the early years, covered 8% (0.9 ha) of the reference area in 2003, but their number and cover have increased significantly in recent years, covered 45% (5.3 ha) of the reference area in 2024 (GLM: $\beta = 1.776$, $SE = 0.101$, $t = 17.615$, $p < 0.001$, Figs. 2, 3 and 6). The first table shows the results of the multinomial logistic regression. The habitat-period model indicated that captures per habitat type of passerines may depend on the capture period. Over

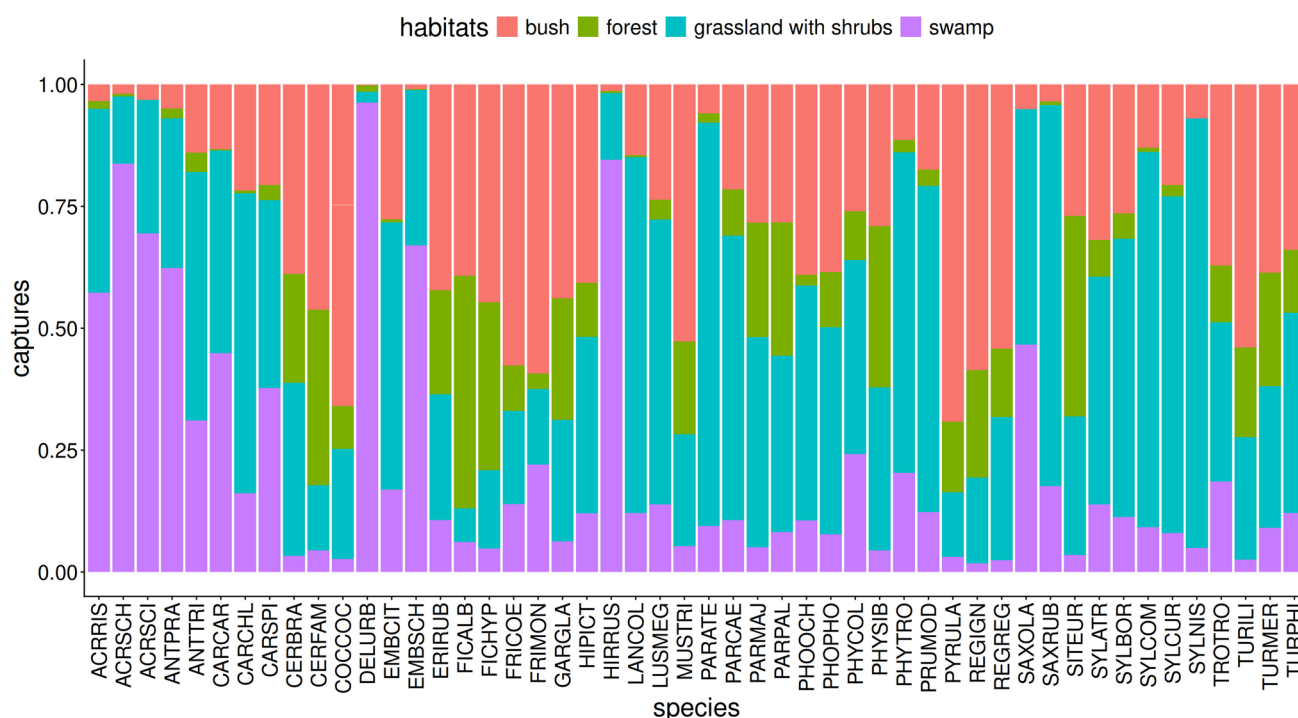


Fig. 4 Relative capture rate per habitat of the fifty passerines. See Table 1 for species abbreviations

the past ten years, several species preferring forest or bushy habitats (e.g., pied flycatcher, wood warbler *Ph. sibilatrix* (Bechstein, 1793), European robin) have been significantly more likely to occur in the swamp than in the bush relative to the beginning of the study period. At the same time, some species prefer open habitats (e.g., meadow pipit, red-backed shrike, common whitethroat *C. communis* (Latham, 1787)) occurred in significantly smaller numbers in the swamp than in the bush with increasing study period. Between 2017 and 2024, there were a few forest species (e.g., common chaffinch *Fringilla coelebs* Linnaeus, 1758, brambling *F. montifringilla* Linnaeus, 1758) that we caught more in the grassland with shrubs than in the bushes over the progression of the study period. There were species (e.g., Eurasian nuthatch, Eurasian treecreeper, coal tit *Periparus ater* (Linnaeus, 1758)) whose habitat-related distribution did not change significantly between 2001 and 2024 (Fig. 7).

Discussion

Habitat-related distribution of species

The canonical correspondence analysis (CCA) results suggest that vegetation structure and coverage may play an important role in shaping the habitat-related distribution patterns of the studied bird species. Optimal canopy density and ground cover are crucial for providing

suitable breeding and post-breeding habitats (Moskát and Waliczky 1992; Luo et al. 2024). The CCA clearly differentiated passerines associated with open grassland or swamp habitats from those preferring dense shrublands and forested areas. Habitat selection in common passerines primarily reflects species-specific ecological requirements (Johnson 2007). Except for generalist species, most species were captured disproportionately in particular habitat types, indicating differences in habitat use during the post-breeding period, likely driven by the uneven distribution of food and shelter sites. This period may involve different habitat requirements compared with the breeding season due to changes in resource availability, flocking behaviour, juvenile movements, and migratory preparation (Hutto 1985). Not all forest-associated species were grouped within the same cluster at the study area. For example, during the post-breeding period, the irruptive migrant coal tit in Hungary (Takács et al. 2021; Bozó 2025) occurred more frequently in shrub–grassland habitats rather than with other forest species. During stopovers, birds prioritize two key objectives: maximizing fat deposition rates and minimizing predation risk (Alerstam and Lindström 1990). Achieving these objectives facilitates timely arrival at subsequent stopover sites and wintering grounds, consistent with the time-minimizing migration strategy (Lindström and Alerstam 1992). Habitat choice is shaped by a hierarchical decision-making process involving both inherited and learned elements. At the broadest scale, innate migratory

Table 1 Odds ratios from multinomial logistic regression models assessing temporal trends in habitat use (habitat type as response variable and study period as a continuous predictor; reference habitat: bush)., * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Species Euring code	Forest	Grassland with shrubs	Swamp
Barn Swallow HIRRUS	0.971	1.011	0.965
Barred Warbler SYLNIS	-	1.097	0.918
Black Redstart PHOOCH	1.009	1.013	1.044*
Brambling FRIMON	1.147***	1.209***	1.260***
Coal Tit PARATE	1.013	0.992	1.002
Collared Flycatcher FICALB	0.992	1.096	1.030
Common Blackbird TURMER	0.999	1.010**	1.059***
Common Chaffinch FRICOE	1.060***	1.105***	1.154***
Common Chiffchaff PHYCOL	0.964***	1.002	1.057***
Common Firecrest REGIGN	0.952***	0.995	1.197**
Common House Martin DELURB	1.000	1.000	1.000
Common Nightingale LUSMEG	0.967	1.040**	0.997
Common Redstart PHOPHO	0.992	0.978	1.007
Common Reed Bunting EMB-SCH	0.854	1.094***	1.027
Common Whitethroat SYLCOM	0.963	0.985*	0.963***
Dunnock PRUMOD	1.041**	1.045***	1.042***
Eurasian Blackcap SYLATR	0.953***	1.011***	1.037***
Eurasian Blue Tit PARCAE	0.996	0.975***	1.021***
Eurasian Bullfinch PYRULA	0.937***	1.079***	1.130***
Eurasian Jay GARGLA	0.962*	0.940***	1.013
Eurasian Nuthatch SITEUR	0.983	0.999	0.968
Eurasian Reed Warbler ACRSCI	-	1.183*	1.222**
Eurasian Siskin CARSPI	0.681***	1.053	1.023
Eurasian Treecreeper CERFAM	0.968	0.971	1.017
Eurasian WrenTROTRO	0.966**	1.026***	1.069***
European Goldfinch CARCAR	0.990	1.062**	1.092***
European Greenfinch CARCHL	0.980	1.005	1.046***
European Pied Flycatcher FYCHIP	0.977***	1.006	1.068***
European Robin ERIRUB	0.984***	1.020***	1.098***
European Stonechat SAXTOR	-	1.082	1.061
Garden Warbler SYLBOR	0.918***	1.011	1.004
Goldcrest REGREG	0.988*	1.058***	1.061***
Great Tit PARMAJ	1.003	1.012***	1.084***
Hawfinch COCCOC	0.999	1.107***	1.133***
Icterine Warbler HIPICT	0.962	1.011	1.008
Lesser Whitethroat SYLCUR	0.934***	0.994	0.936***
Marsh Tit PARPAL	0.988	0.975	1.008
Marsh Warbler ACRRIIS	0.852*	1.051	1.056
Meadow Pipit ANTPEA	0.462	1.172*	1.075
Red-backed Shrike LANCOL	0.933	1.018*	0.969**
Redwing TURILI	0.931***	1.088***	1.167***
Sedge Warbler ACRSCH	1.332***	1.174***	1.158***
Short-toed Treecreeper CERBRA	0.983	0.961**	1.055
Song Thrush TURPHI	1.001	1.018***	1.050***

Table 1 (continued)

Species Euring code	Forest	Grassland with shrubs	Swamp
Spotted Flycatcher MUSSTR	0.955***	0.981	0.951**
Tree Pipit ANTTRI	0.889***	0.910***	0.958***
Whinchat SAXRUB	0.138***	0.944	0.868**
Willow Warbler PHYTRO	0.969	0.993	0.998
Wood Warbler PHYSIB	1.017	1.006	1.178***
Yellowhammer EMBCIT	0.940*	1.020***	0.984**

programs guide birds along specific migration routes toward large geographic regions (e.g., Southern Europe or North Africa). At an intermediate scale, birds select habitat types (e.g., coniferous or deciduous forests), and at the finest scale, individuals occupy specific microhabitats. Microhabitat selection combines innate preferences with experience gained through local exploration (Hutto 1985).

During migration, insectivorous species often show habitat-specific preferences based on foraging requirements. For example, garden warblers *Sylvia borin* (Boddaert, 1783) favor sugar-rich shrubs such as dwarf elder for energy intake and rest (Bairlein 1985), often clustering in open grasslands with scattered shrubs that resemble their savanna wintering habitats. In contrast, sedge warblers feed exclusively on insects in marsh vegetation, leading spotted reed warblers to aggregate in swampy habitats during autumn migration (Chernetsov 1998; Gyur  cz and Bank 2000). Fragmentation of wetland habitats in recent decades has contributed to increased sedentariness among wetland-associated species during migration (Cantos and Telleria 1994). Short-distance migrants, particularly those wintering in the Mediterranean or in parts of Hungary, remain in the study area throughout autumn migration, often occupying dense scrub habitats (Gyur  cz et al. 2012). Their slower migration and longer stopover duration increase the importance of predation avoidance. Dense, thorny vegetation provides effective protection from avian predators, allowing birds to maximize safety while maintaining access to subsequent resting sites (Chernetsov 2012; Berthold 2001). Our findings on the habitat-associated distribution patterns of the studied bird species provide evidence of habitat selection patterns during post-breeding period; however, potential underlying mechanisms, including competition and selection processes, should be regarded as possible explanatory factors that require further investigation (Kelly et al. 2002; Ottich and Dierschke 2003; Salewski et al. 2007).

Changes in the vegetation and habitat-related distribution of species

Our earlier study demonstrated an abundance-dependent shift in habitat-related distribution during the

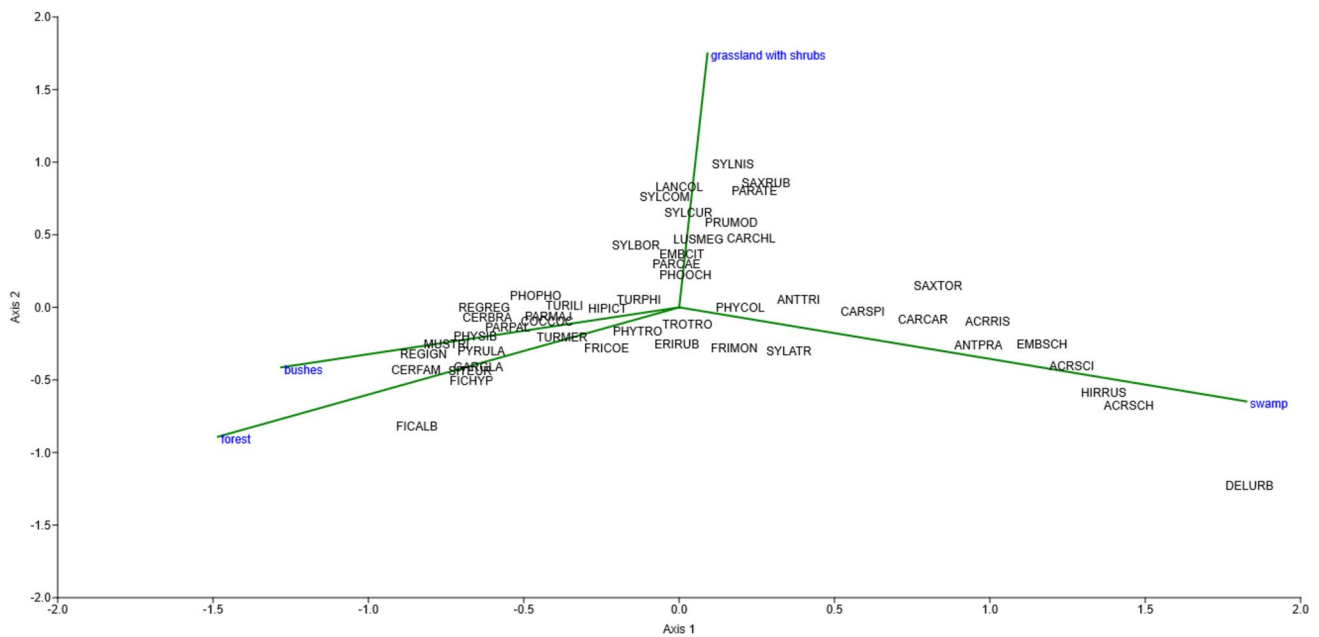


Fig. 5 Ordination biplot depicting the first axes of the CCA of the captures of bird species in relation to habitat types (arrows). See Table 1 for species abbreviations. The length of habitat type vectors indicates their relative strength in explaining variation in the numbers

of species. The distance from the origin to the perpendicular drawn from the bird species code to a habitat type vector indicates how closely associated that bird with that habitat

post-breeding period (Gyurácz et al. 2012). The present study highlights the influence of long-term vegetation

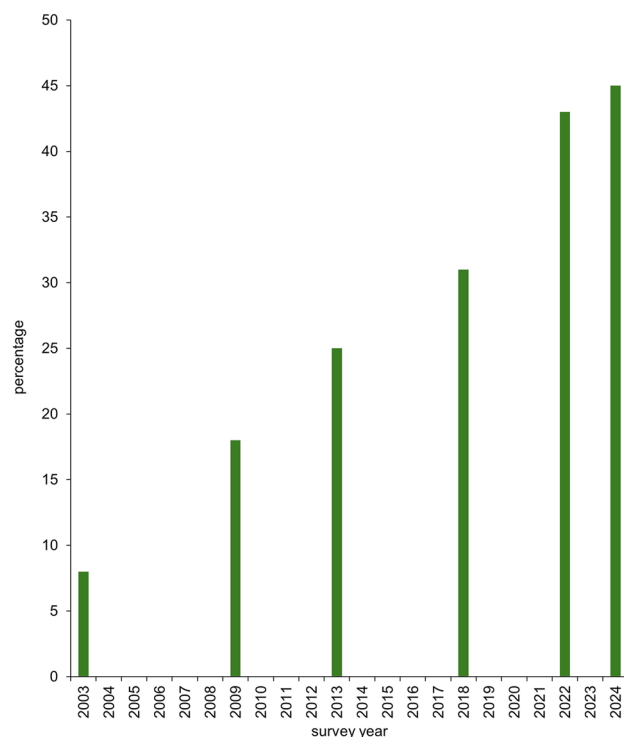


Fig. 6 Changes in woody vegetation cover within the reference area across the surveyed years

changes on habitat selection among migratory birds during this period. In the marsh, the expansion of dense willow bushes between 2017 and 2024 has progressively closed the habitat. Similarly, the abandonment of former arable fields around the swamp has allowed tall grasses to develop, gradually giving way to shrubs. Wild roses *Rosa canina* LINNAEUS, 1753, blackthorns, and hawthorns further contribute to habitat closure. The spread of wild fruit trees, primarily wild pear *Pyrus pyraeaster* (L.) Burgsdorf, 1753 and crab apple *Malus sylvestris* (L.) Miller, 1768, is driven by seed dispersal by birds and mammals. Over time, wild pear and crab apple trees increasingly dominate areas previously occupied by wild rose bushes, which often decline due to shading (Németh 2019). At least two successional stages are evident. In older shrub belts, protected by dense vegetation, crab apple and wild pear trees coexist with emerging oak, wild cherry *Prunus avium* Linnaeus, 1753, field maple *Acer campestre* Linnaeus, 1753, and common ash *Fraxinus excelsior* Linnaeus, 1753 trees. These trees escape browsing by deer and grow undisturbed, forming the early stages of future forest patches. At forest edges, hawthorns persist but struggle to survive under the shaded canopy. In some western areas, succession has advanced to the point where only the dead stumps of former shrubs remain beneath the closed canopy (Németh 2019).

Our habitat-period model analyses provide evidence that successional dynamics in vegetation structure may

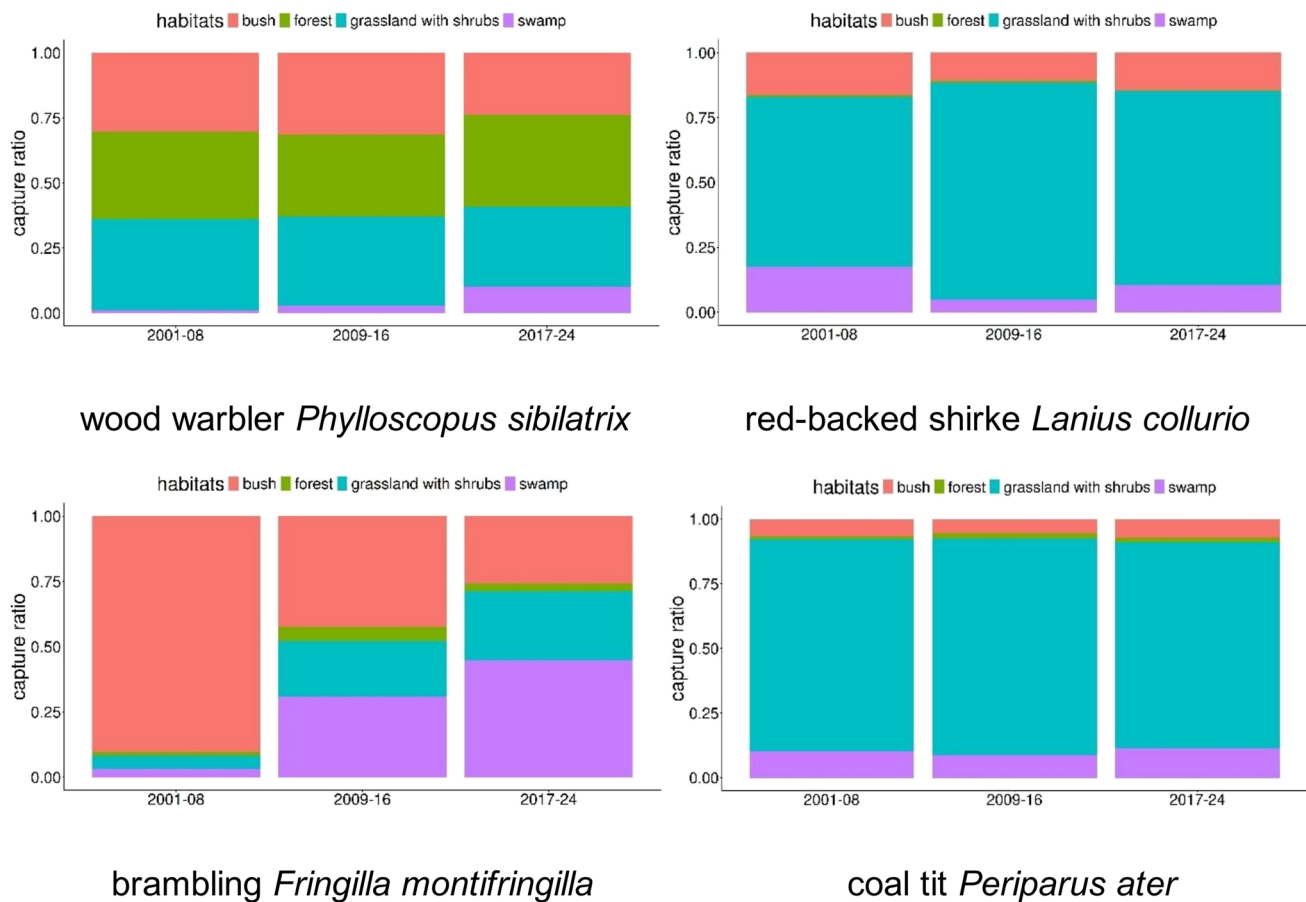


Fig. 7 Capture rates (standardized captures in a given habitat type/total captures during the study periods: 2001–2008, 2009–2016, 2017–2024) of four bird species across the three study periods

influence patterns of avian distribution observed during the post-breeding period. As vegetation becomes denser, species favoring shrub habitats (e.g., Eurasian hawfinch, *Coccothraustes coccothraustes* (Linnaeus, 1758), common firecrest) and forest specialists (e.g., wood warbler, European pied flycatcher) increase in abundance within the swamp. Conversely, species preferring open habitats (e.g., red-backed shrike, whinchat) decline. It should be noted that our results pertain to dispersal and autumn migration periods, during which habitat selection is influenced more by food availability, shelter, and climatic conditions than by breeding requirements (Cunningham et al. 2022).

Our findings demonstrate that bird species differ in their use of habitat types during the post-breeding period, highlighting the importance of maintaining habitat heterogeneity in agricultural landscapes. These results provide ecological information that may assist habitat management and conservation planning, although further studies evaluating additional environmental factors are needed before specific management recommendations can be made. (Cai et al. 2014). Our results support the implementation of targeted

protection and restoration measures to mitigate habitat loss and fragmentation. Future research could further explore differences in bird habitat selection between patchy and continuous habitats, providing a stronger scientific foundation for bird conservation and ecosystem management.

Conclusions

Our findings identify the key habitat characteristics and vegetation attributes influencing avian habitat selection and demonstrate pronounced interspecific variation in responses to habitat structure. The heterogeneous plant communities within the study area, comprising open grasslands, shrub-dominated patches, and marsh vegetation, provide critical resting and foraging resources for a diverse assemblage of bird species during the post-breeding period. Our results suggest the fundamental role of vegetation structure and habitat complexity in shaping species distribution patterns and habitat use during this transitional phase of the annual cycle. The long-term maintenance of such heterogeneous mosaic

landscapes requires targeted conservation management, including selective shrub removal and periodic mowing, to prevent vegetation encroachment and sustain the availability of both open and structurally complex habitats. These management interventions are essential for maintaining the ecological functionality of the study site as a resting, feeding and shelter habitat supporting a broad range of migratory and resident bird species.

Acknowledgements We would like to thank all those who took part in the fieldwork and the members of BirdLife Hungary for the bird ringing and the data collection work. We are also grateful to Sara Oakeley for comments on the manuscript. This paper is part of the South-East Bird Migration Research Network and Actio Hungarica publications.

Author contribution J.Gy., P.M. wrote the main manuscript text and S.K. 1–3. prepared figures. All authors participated in data collection and reviewed the manuscript.

Funding Open access funding provided by Eötvös Loránd University.

Data availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval All bird captures and handling were approved by the Hungarian Bird Ringing Centre, BirdLife Hungary, Budapest, Hungary (permit Budapest Government Office PE-KTF/97–13/2017), and in compliance with Hungarian laws and regulations.

Competing interests The authors declare no competing interests.

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