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HABITAT SUITABILITY AND SPATIAL DISTRIBUTION OF RED-BACKED SHRIKES *LANIUS COLLURIO* IN TWO PROTECTED SITES IN SOUTHERN CENTRAL EUROPE

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Taylor, L., Kralj, J., Hadžalić, S., Blažević, A., Matijević, D., Jevšnik, E., Kopinič, J. & Tome, D.: Habitat suitability and spatial distribution of Red-backed shrikes *Lanius collurio* in two protected sites in Southern Central Europe. Nat. Croat., Vol. 35, No. 2, _____, 2026, Zagreb.

The Red-backed Shrike *Lanius collurio* is a widespread breeding species in Croatia and Slovenia. It breeds primarily in mosaic agricultural landscapes and grasslands, and its populations have declined in some areas due to land abandonment and subsequent overgrowth. Within the Nature Park Žumberak–Samoborsko gorje in Croatia and the Kozjansko Regional Park in Slovenia, the species remains a common breeder; however, its distribution in both areas is poorly known. Using species distribution modelling, we identified areas with a high probability of occurrence. The model indicated that grassland cover and the presence of small woody features are the most important habitat variables influencing species occurrence. Furthermore, the Kozjansko Park contained a larger proportion of areas with a high predicted probability of occurrence for the Red-backed Shrike. The areas of predicted occurrence probability were more fragmented in the Nature Park Žumberak–Samoborsko gorje than in the Kozjansko Regional Park, with patches being more numerous, smaller, and more isolated.

Keywords: Random Forest, grasslands, species distribution modelling, land management, fragmentation, isolation

Taylor, L., Kralj, J., Hadžalić, S., Blažević, A., Matijević, D., Jevšnik, E., Kopinič, J. & Tome, D.: Prikladnost staništa i prostorna rasprostranjenost rusog svračka *Lanius collurio* u dva zaštićena područja južne središnje Europe. Nat. Croat., Vol. 35, No. 2, _____, 2026, Zagreb.

Rusi svračak *Lanius collurio* široko je rasprostranjena gnjezdarica u Hrvatskoj i Sloveniji. Gnijezdi se ponajprije u mozaičnim poljoprivrednim krajobrazima i travnjacima, a u nekim je područjima došlo do smanjenja brojnosti populacije zbog napuštanja tradicionalnog korištenja zemljišta i njegova zarastanja. Unutar Parka prirode "Žumberak–Samoborsko gorje" u Hrvatskoj i Regionalnog parka Kozjansko u Sloveniji vrsta je i dalje česta gnjezdarica, no njezina je rasprostranjenost u pojedinim dijelovima tih područja slabo poznata. Korištenjem modeliranja rasprostranjenosti vrsta identificirana su područja s visokom vjerojatnošću pojavljivanja. Model je pokazao da su pokrov travnjaka i prisutnost manjih drvenastih elemenata najvažnije značajke staništa koje utječu na pojavljivanje vrste. Nadalje,

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Kozjanski park sadrži veći udio područja s visokom predviđenom vjerojatnošću pojavljivanja rusih svračaka. Područja s predviđenom vjerojatnošću pojavljivanja bila su fragmentiranija u Parku prirode "Žumberak–Samoborsko gorje" nego u Regionalnom Parku Kozjansko, pri čemu su fragmenti staništa bili brojniji, manji i međusobno izoliraniji.

Ključne riječi: Random Forest, travnjaci, modeliranje rasprostranjenosti vrsta, upravljanje staništima, fragmentacija, izolacija

INTRODUCTION

As a result of several millennia of human presence in Europe, the majority of European grasslands have been created and managed by humans to provide food for livestock (GORRIS *et al.*, 2025). If adequately managed, these semi-natural grasslands may host high plant and animal biodiversity. The importance of grasslands is immense; apart from providing food for livestock, they are important habitats for pollinators, they host medicinal and culinary herbs, and are homes to many threatened plant and animal species (BOVAL & DIXON, 2012). Grasslands are today threatened by two opposite forces: agricultural intensification and land abandonment (BRAMBILLA *et al.*, 2007). Agricultural intensification, which includes fertilisation, mechanisation, sowing of commercial grasses, and intensive grazing or mowing, reduces plant diversity by decreasing the number of flowering plants while favouring the prevalence of grasses. Together with the conversion of meadows to arable land with large-scale monocultures or to other land uses, results in a rapid decrease in biodiversity. In contrast, land abandonment, often the result of the depopulation of rural landscapes, leads to succession, overgrowth, and fragmentation of grasslands. The spread of invasive plant species, such as the indigo bush *Amorpha fruticosa*, additionally speeds up the process of overgrowth. Fragmentation is the process by which a continuous habitat is broken into smaller, isolated patches (WILCOVE, 1986). This process involves four main effects: a reduction in the total habitat area, an increase in the number of habitat patches, a decrease in patch size, and increased isolation among patches (FAHRIG, 2003). Habitat fragmentation has a strong negative impact on biodiversity, primarily due to habitat loss and reduced connectivity.

Among all European breeding birds, agricultural and grassland species have exhibited the largest population declines (BURNS *et al.*, 2021). The decline in the populations of grassland and farmland birds has been more pronounced in Western Europe following the implementation of the EU Common Agricultural Policy. In Central and Eastern Europe, decline is slower, and often related to land abandonment and land-use changes (TRYJANOWSKI *et al.*, 2011), although after joining the EU those countries also experience problems of the Common Agricultural Policy (SUTCLIFE *et al.*, 2015)

The Red-backed Shrike *Lanius collurio* inhabits mosaic agricultural landscapes, depending on biodiversity-rich grasslands for foraging and scattered, dense, often thorny bushes and low trees for nesting (YOSEF *et al.*, 2020). It is listed under Annex I of the EU Birds Directive (Directive 2009/147/EC) and is often used as an indicator of grassland biodiversity (TRYJANOWSKI *et al.*, 2011). Population densities are generally low, typically not exceeding 5 breeding pairs km² over large areas, although local densities may exceed 100 breeding pairs km² in particularly suitable habitats (CRAMP & SIMMONS, 2006). Population densities are generally low, typically not exceeding 5 breeding pairs km² over large areas, although local densities may exceed 100 breeding pairs km² in particularly suitable habitats (CRAMP & SIMMONS, 2006). Although widely distributed in Europe, its population has drastically declined in number and range during the 20th century (TUCKER & EVANS, 1997). The main cause was agricultural intensification, which included the use of pesticides and fertilisers and

the loss of marginal vegetation (hedgerows and solitary bushes). As a predator, it depends on the presence of large insects, rodents, and other small vertebrates. Recently, its population is considered stable at the continental level (BirdLife International 2024), with population and range increases in some areas and decreases in others (VAN NIEUWENHUYSE & DE MIDDELEER, 2024; LOBNIK *et al.*, 2025).

The distribution of the Red-backed Shrike within the Nature Park Žumberak–Samoborsko gorje is poorly documented. The avifauna of the area was first described in the 1970s (RUCNER, 1975), and only a few subsequent studies have covered parts of the species' range (DUMBOVIĆ RUŽIĆ & ŠĆETARIĆ LEGAN, 2003; KRALJ *et al.*, 2007, 2008). In contrast, the species has been well documented in the Kozjansko Regional Park, where it is listed as a Natura 2000 species. An estimated 2,300–3,200 breeding pairs occur within Kozjansko Park (JANČAR & TREBUŠAK, 2000). The population appears to be stable (GAMSER 2020), with noticeable fluctuations (KMECL *et al.*, 2014). Declining trends have been reported at the national level in Croatia (BUDINSKI *et al.*, 2022), while at the national level in Slovenia, the population is stable, with a decline in some local areas (KMECL & GAMSAR, 2025; LOBNIK *et al.*, 2025). The aim of this study was to identify the potential distribution of the species in both protected areas, determine the habitat features preferred by the Red-backed Shrike, and assess differences between the two study areas, with particular emphasis on higher-elevation zones. In addition, we examined the degree of fragmentation of areas with high predicted occurrence and compared fragmentation patterns between the two study sites to analyse which areas are at greater risk of losing open habitats.

MATERIALS AND METHODS

The Nature Park Žumberak – Samoborsko gorje (later referred to as Žumberak – Samoborsko gorje) is located in northwestern Croatia, where the characteristics of the Dinarides, Alps, and Pannonian Plain intersect. The Dinaric influence is evident in the karst relief, the Alpine influence appears in the steep and sharp mountain ridges, and the gentle, undulating hills reflect the features of the Pannonian landscape. Žumberak – Samoborsko gorje covers a total area of 342.26 km², with elevations ranging from 180 m above sea level in the Kupa River valley to 1,178 m at the peak of Sveta Gera. Forests are the most widespread habitat type, covering approximately 60% of the area. Non-forest habitats make up 36.5% of Žumberak – Samoborsko gorje. Of this, arable land accounts for approximately 21%, orchards 4%, vineyards 5%, meadows 37%, and pastures 33%. Unlike forests, most grassland habitats were created through deforestation to provide agricultural land and pasture and are thus strongly shaped by human activity. From 1958 to 2011, the resident population within Žumberak – Samoborsko gorje continuously declined from 15,817 to 3,327 inhabitants (JAVNA USTANOVA „PARK PRIRODE ŽUMBERAK - SAMOBORSKO GORJE“, 2017). The decline in population probably influenced a decrease in the area of non-forested habitats, and they are likely less widespread today.

Kozjansko Regional Park (later referred as Kozjansko Park) is one of the oldest and largest protected areas in Slovenia, located in the eastern part of the country between the Sotla River and the Bohor range. It covers a total area of 206.50 km², with elevations ranging from 151 m above sea level at the Figar Bridge on the Sotla River to 860 m at the summit of Oslica. Forests cover almost half of the park's area. The remaining habitats include dry mountain meadows at the highest points, pre-alpine areas of the park, meadow orchards which are characterised by extensive use of agricultural land, wet meadows that are relatively scarce

within the area, and agricultural landscapes. The landscape of Kozjansko Park includes 78 settlements, with a population of approximately 10,700 recorded in 2002 (KOZJANSKI PARK, 2025). Non-forest habitats within both areas are threatened due to changes in agricultural land use, abandonment of cultivation and subsequent overgrowth, economic changes, and changes in the social structure of the owners (JAVNA USTANOVA „PARK PRIRODE ŽUMBERAK - SAMOBORSKO GORJE“, 2017; KOZJANSKI PARK, 2025). The areas are 13 kilometers apart from each other.

Data were collected during the breeding seasons of 2024 and 2025 in Croatia and Slovenia using the point-count method (BIBBY *et al.*, 2012) and nest searching. We censused 48 points in Kozjansko Park and 43 in Žumberak – Samoborsko gorje during May and June, on meadows to locate breeding pairs. Points were selected on grasslands. Point counts had two bands, within 50 meters and outside 50 meters from the observer; however, we used only the data gathered within 50 meters, so that the observations were within the appropriate 100 x 100 m cell. Red-backed Shrikes can be detected several hundred metres from an observation point, and because exact distances were not recorded, individuals observed beyond the 50 m radius were excluded from the analysis to reduce spatial uncertainty. In several cases, nests and breeding territories were subsequently confirmed for the excluded individuals. Red-backed Shrikes were recorded at 22 points in Žumberak – Samoborsko gorje (51% of surveyed points) and 30 points in Kozjansko Park (62% of surveyed points). Additionally, 58 active nests or territories were located in Žumberak – Samoborsko gorje and 22 in Kozjansko Park. In total, we used 132 observation points.

For habitat variables, we used raster layers with a 10 m resolution for habitat cover (ZANAGA *et al.*, 2022) and a 5 m resolution layer of small woody features (layer contain information about linear and patchy woody vegetation outside forest, isolated/scattered patches of trees areas, storm damages, linear hedgerows and scrubs and tree rows, LANGANKE, 2019). These layers were aggregated to 100 x 100 m, and we calculated the percentage cover of each variable within every grid cell. We included habitat cover of grasslands, tree cover, cropland, shrubland, built-up areas, bare or sparse vegetation, and permanent water bodies. In addition to habitat variables, we used elevation, heat load index, topographic roughness, surface relief ratio, slope, precipitation, and temperature variables (JARVIS *et al.*, 2008; FICK & HIJMANS, 2017; HIJMANS *et al.*, 2024). These variables were in a resolution of 30 arc seconds (approximately 1x1km), and we aggregated their mean values to the same 100 x 100 m grid.

Species distribution modelling (SDM) was performed using a Random Forest algorithm with the packages *sf*, *spatialEco*, *terra*, *ranger*, *randomForest*, *rfUtilities*, and *pdp* (LIAW & WIENER, 2002; GREENWELL, 2017; WRIGHT & ZIEGLER, 2017; EVANS & MURPHY, 2020, 2025; PEBESMA & BIVAND, 2023; HIJMANS, 2025). All figures were produced using QGIS and R, specifically the *ggplot2* package (WICKHAM, 2016; QGIS DEVELOPMENT TEAM, 2023; R CORE TEAM, 2024). Seventeen observations fell within cells that already contained another observation. Therefore, we used 115 grid cells with Red-backed Shrike records as presence data and 128 cells as pseudo-absence data, resulting in an approximately 50% proportion of presences (LIU *et al.*, 2005). The spatial distribution of presence and pseudo-absence cells used for model development is shown in Fig. 1. To reduce the likelihood of selecting locations associated with known breeding territories, all pseudo-absence points were constrained to be at least 500 m from any presence record. All environmental variables were initially evaluated, after which highly correlated variables were removed and only the variables retained by the selection procedure were included in the final Random Forest model. Model stability was

assessed using 1001 bootstrap iterations. In each iteration, approximately 10% of the presence records and 10% of the pseudo-absence records were randomly withheld for validation, while the remaining data were used for model training. Model performance metrics were then calculated across all bootstrap iterations.

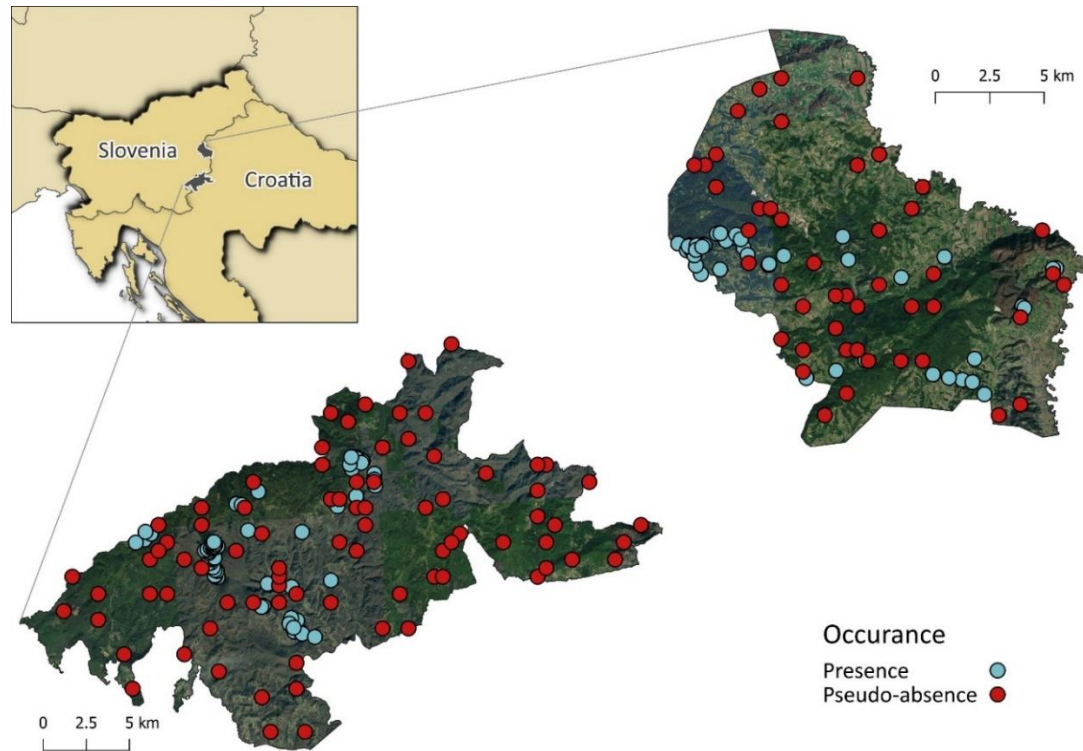


Fig. 1. Spatial distribution of Red-backed Shrike presence and pseudo-absence cells used for species distribution modelling.

Fragmentation of the high probability of estimates for the species distribution was analysed using the R package *landscapemetrics* (HESSELBARTH *et al.*, 2019), which implements metrics originally developed in *FRAGSTATS* (MCGARIGAL *et al.*, 2023). Using this package, we calculated the number and area of all patches, the largest patch index (i.e., the percentage of the landscape covered by the largest patch), and the patch cohesion index (SCHUMAKER, 1996), which characterises the connectedness of patches and indicates whether patches are aggregated or isolated. Patches are regarded all cells that are touching, regardless of their size. In addition, we calculated the Euclidean distance to the nearest neighbouring patch for both study areas. To test for differences between the two study areas in terms of patch area and nearest-neighbour distance, we used the Mann–Whitney U test.

RESULTS

The algorithm selected grasslands, small woody features, built-up areas, and minimum temperature as the most important parameters for the SDM, with grasslands contributing the most (Fig. 2). The mean values and standard deviations of the variables retained in the final model for presence and pseudo-absence cells are presented in Tab. 1. The model validation results are presented in Tab. 2.

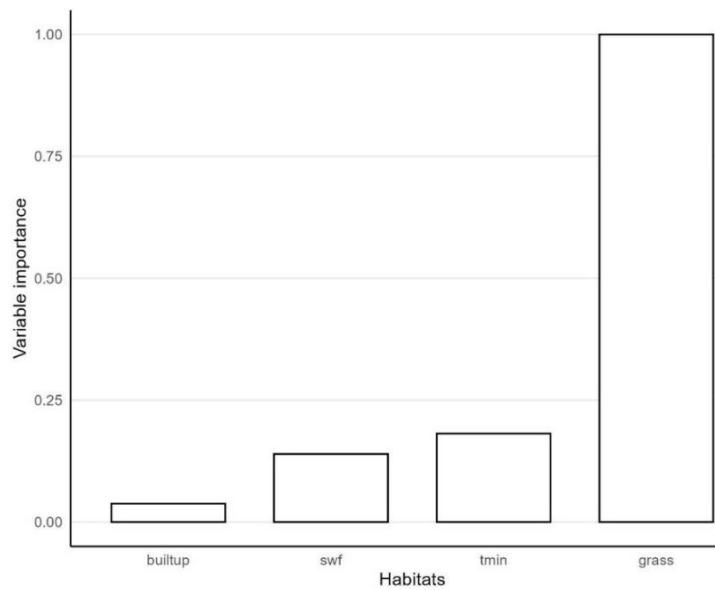


Fig. 2. Selected parameters and their variable importance that contributed to the SDM of Red-backed Shrike (grass = grasslands, tmin= minimum temperature, swf = small woody features, builtup = built-up areas).

Tab. 1. Mean values ($\pm$ SD) of variables retained in the final Random Forest model for presence and pseudo-absence cells.

Variable	Presence Mean $\pm$ SD	Pseudo-absence Mean $\pm$ SD
Built-up	0.0127 $\pm$ 0.0481	0.0043 $\pm$ 0.0170
Grassland	0.6000 $\pm$ 0.2383	0.1223 $\pm$ 0.2204
Small woody features	0.0743 $\pm$ 0.0794	0.0236 $\pm$ 0.0618
Tmin	3.75 $\pm$ 0.78	4.11 $\pm$ 0.76

Tab. 2. Model validation metrix for the SDM of Red-backed Shrikes *Lanius collurio* within Nature Park Žumberak – Samoborsko gorje and Kozjansko Regional Park

Model validation	Fit
Percent Correctly Classified	98.745
Kappa	0.975
Log loss	0.098
Brier score	0.023
Sensitivity	1
Specificity	0.974
Area Under ROC (AUC)	0.987
Type I error	0.026
Type II error	0
Information Gain (signal to noise)	0.989
Performance (cross-validation)	
Cross-validation error	0.061
Cross-validation log loss	0.199
Cross-validation Brier Score	0.067
Cross-validation sensitivity	0.917
Cross-validation specificity	0.833
Cross-validation kappa	0.833

In the Žumberak – Samoborsko gorje, habitat cover consisted primarily of forest (93.9%), with grasslands accounting for 5.6%, and all remaining habitat types comprising only 0.4%. In contrast, Kozjansko Park exhibited a more heterogeneous landscape, with 62.1% forest, 29.6% grassland, 7.3% cropland, 0.9% built-up areas, and 0.04% distributed among other habitat types (Fig. 3).

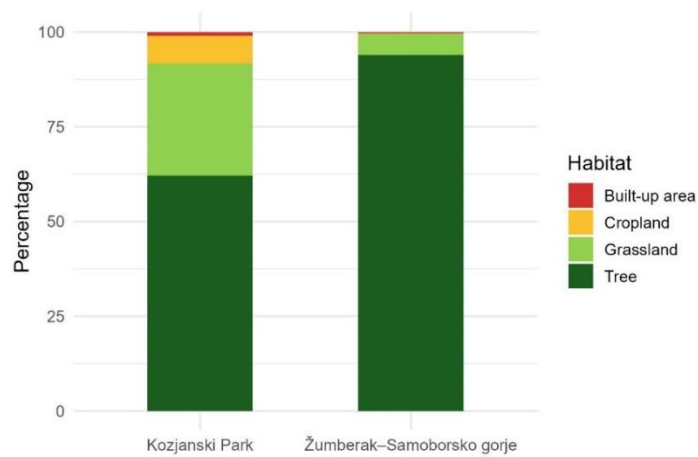


Fig 3. Differences of habitat cover percentage between Kozjansko Regional Park and Nature Park Žumberak – Samoborsko gorje from ESA WorldCover habitat cover (ZANAGA *et al.*, 2022).

We selected cells with a probability estimate greater than 50% as having a high probability. The SDM identified 101.2 km² as having a high probability of Red-backed Shrike occurrence, representing 34.2% of the total area of Kozjansko Park (69.4 km²) and 9.3% in Žumberak – Samoborsko gorje (31.8 km²) (Fig. 4).

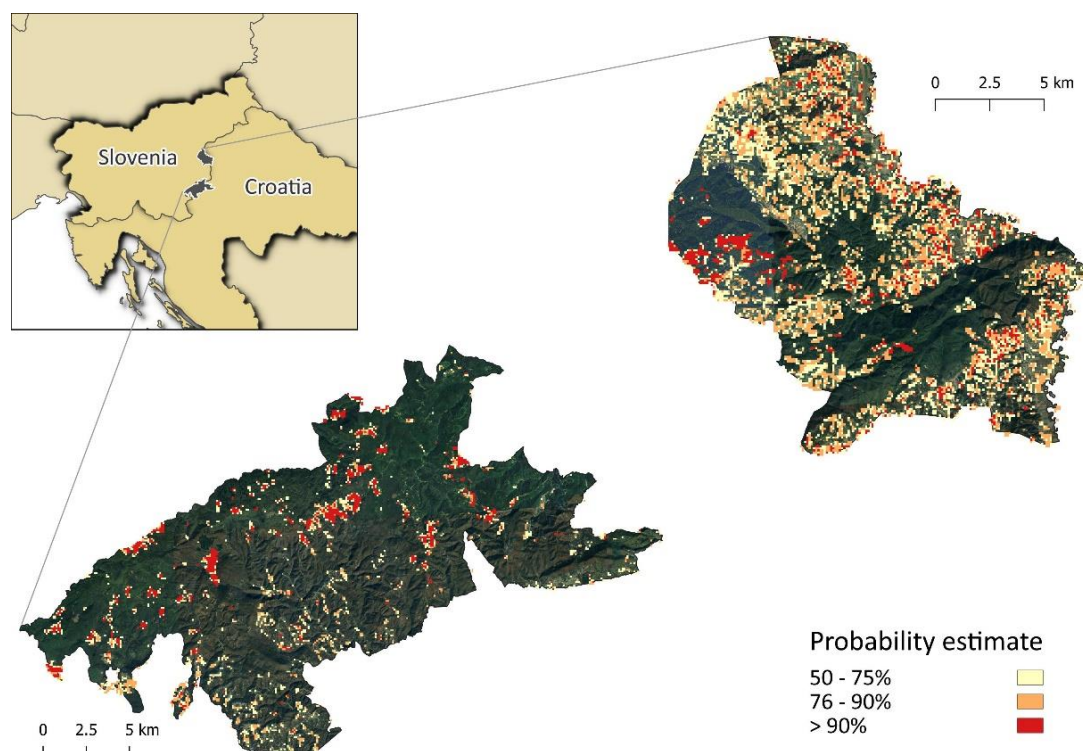


Fig. 4. Predicted suitable areas for Red-backed Shrikes *Lanius collurio* with occurrence probabilities exceeding 50% within Nature Park Žumberak-Samoborsko gorje and Kozjansko Regional Park. Areas without coloured prediction values represent locations with predicted probabilities below the selected threshold and are shown only as the underlying satellite imagery.

Fragmentation metrics revealed a total of 283 patches were identified in Kozjansko Park, compared to 400 patches in Žumberak – Samoborsko gorje. The mean patch area in Kozjansko Park was 23.63 ha (SD = 98.79, range: 1–1,173 ha), whereas in Žumberak – Samoborsko gorje it was 7.58 ha (SD = 16.07, range: 1–188 ha). Patch areas differed significantly between the two study sites ($W = 49,133$, $Z = -2.98$, $p = 0.003$) with a small effect size ($r = 0.11$).

The largest patch index indicated that the largest patch covered 0.53% of the total patch area in Žumberak – Samoborsko gorje compared with 5.61% in Kozjansko Park. Kozjansko Park also exhibited a higher patch cohesion index (94.08%) than Žumberak – Samoborsko gorje (76.29%), indicating greater connectivity among patches.

The mean Euclidean nearest-neighbour distances between patches were 237.82 m in Kozjansko Park (SD = 95.73, range: 200–989.95 m) and 336.92 m in Žumberak – Samoborsko gorje (SD = 215.90, range: 200–2,202.27 m). Nearest-neighbour distances differed significantly between the two study sites ($W = 82,278$, $Z = 10.47$, $p < 0.001$), with a moderate effect size ($r = 0.40$).

DISCUSSION

Our model identified grasslands, small woody features, and built-up areas as the most important variables influencing the distribution of the Red-backed Shrike. The importance of temperature may partly reflect the concentration of occurrence records in higher-elevation areas, where temperature and elevation are strongly correlated. Consequently, predicted occurrence probabilities were lower at lower elevations in both Kozjansko Park and Žumberak – Samoborsko gorje. However, many open habitats at lower altitudes still showed occurrence probabilities exceeding 50%, indicating that habitat suitability predictions were influenced by multiple environmental and habitat variables rather than by temperature alone.

The remaining key variables, namely grasslands, small woody features and built-up areas, are consistent with the known habitat preferences of the Red-backed Shrike. The species requires low vegetation for foraging and shrubs for nesting (CRAMP & SIMMONS, 2006) and typically favours heterogeneous landscapes composed of meadows and open habitats interspersed with shrub cover (BRAMBILLA *et al.*, 2007; LOBNIK *et al.*, 2025). Grassland cover emerged as the most important variable in our model, highlighting the significance of open habitats for the species in both study areas. Small woody features were strongly associated with shrubland cover and included shrubs, young trees, and orchard elements, which provide essential nesting sites. In the study areas, many orchards consist of scattered mature fruit trees surrounded by grasslands. These trees often provide dense branching structures suitable for nesting of Red-backed Shrikes. Because these features often occupy only a small proportion of a grid cell despite their ecological importance for nesting, their contribution may be underestimated by habitat-cover metrics based on percentage areas.

The influence of built-up areas in the model may reflect the association of suitable open habitats and small woody features with areas under moderate anthropogenic influence, particularly in the vicinity of human settlements. In contrast, open habitats located farther from settlements are frequently abandoned and subject to shrub encroachment, making them unsuitable for the species. Previous studies have shown that Red-backed Shrike may avoid intensively managed croplands, although responses depend on local agricultural practices and landscape structure (BRAMBILLA *et al.*, 2007). Although the species is known to occur in

agricultural landscapes containing shrubs or hedgerows (CRAMP & SIMMONS, 2006), cropland cover itself was not identified as an important predictor in our model.

The present model considers environmental predictors only. Local breeding distributions may additionally be influenced by social processes such as conspecific attraction, which were not included in the modelling framework (VAN NIEUWENHUYSE & DE MIDDELEER, 2017).

Kozjansko Park contained a larger proportion of open habitats than Žumberak – Samoborsko gorje, which is reflected in the model predictions. Despite being approximately 60% smaller in area, Kozjansko Park contained more than twice the total area of predicted suitable habitat compared with Žumberak – Samoborsko gorje. In contrast, the predicted suitable areas in Žumberak – Samoborsko gorje were more fragmented, characterised by a higher number of patches, significantly smaller patch sizes, and a smaller largest patch relative to the total suitable habitat area. Habitat overgrowth and changes in habitat structure can cause fragmentation, resulting in a larger number of smaller habitat patches that may become too small to sustain local populations (FAHRIG, 2003). Additionally, the greater nearest-neighbour distances observed in Žumberak – Samoborsko gorje indicate that suitable habitat patches are more spatially separated than in Kozjansko Park.

A primary driver of habitat loss and fragmentation in both study areas is the decline in resident human populations and associated socioeconomic changes, resulting in fewer people engaged in agricultural activities (JAVNA USTANOVA „PARK PRIRODE ŽUMBERAK - SAMOBORSKO GORJE“, 2017; KOZJANSKI PARK, 2005). This process leads to land abandonment, in which open habitats gradually transition into shrubland and forest, negatively affecting grassland-dependent species. Such changes impact not only breeding species but also species that rely on open habitats for foraging, including the Red-backed Shrike (LOBNIK *et al.*, 2025; SCRIDEL *et al.*, 2025).

Although quantitative data on breeding pair numbers are lacking for Žumberak – Samoborsko gorje, previously reported fluctuation in the Red-backed Shrike population of Kozjansko Park (KMECL *et al.*, 2014), combined with the higher degree of fragmentation, smaller patch sizes, lower patch cohesion, and greater spatial separation of suitable habitat patches, as well as pronounced depopulation, agricultural abandonment and ongoing habitat overgrowth in Žumberak – Samoborsko gorje, suggests that Red-backed Shrikes in this area may be at greater risk.

To mitigate further habitat loss, conservation measures should be implemented in both protected areas. Previous studies have shown that intensive agricultural practices involving pesticide and fertiliser use can negatively affect Red-backed Shrike habitat quality (LOBNIK *et al.*, 2025). Consequently, the maintenance of low-intensity agricultural management may be particularly important in the lowland areas of Kozjansko Park, where agricultural land is more extensive. Meadows should be managed in ways that maintain prey-rich grassland habitats and functional food webs, benefiting both Red-backed Shrikes and a wide range of grassland organisms (SVENDSEN *et al.*, 2015; KNOZOWSKI *et al.*, 2024; LOBNİK *et al.*, 2025).

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