Protected area networks are insufficient for the conservation of threatened farmland species: a case study on corncrake (*Crex crex*) and lesser grey shrike (*Lanius minor*) in Serbia

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Received: September 24, 2018; **Revised**: November 25, 2018; **Accepted**: November 28, 2018; **Published online**: December 4, 2018

Abstract: To conserve threatened farmland species requires an estimate of the representation of their habitats within protected areas, especially in countries with inadequate mechanisms for protecting and managing habitats outside of protected areas. We conducted a gap analysis to evaluate the conservation status of suitable habitats for two threatened farmland bird species — corncrake (*Crex crex*) and lesser grey shrike (*Lanius minor*) — within the networks of national protected areas (NPAs) and important bird areas (IBAs) in Serbia. We determined the distribution of suitable habitats using MaxEnt based on climate, topography and land-cover variables. We found that the proportion of suitable habitats within the NPAs is very low (12.31% and 2.04% for the corncrake and lesser grey shrike, respectively), although it is significantly higher for both species within IBAs (25.86% and 9.91%, respectively). Upland farmland habitats (preferred by corncrake) are better represented within both networks (especially IBAs) than lowland habitats (preferred by lesser grey shrike). Our spatially explicit distribution models identify suitable habitats within and beyond the NPAs and IBAs that require monitoring and appropriate conservation measures. The low representation of suitable habitats within these networks is an obstacle to the conservation of both species and other farmland birds in Serbia.

Keywords: farmland birds; protected areas; *Lanius minor*; *Crex crex*; gap analysis

INTRODUCTION

Declining farmland biodiversity has been well documented worldwide, but especially in Europe and North America [1-3]. Population declines among farmland birds in the European Union (EU) is a clear example of the impact that application of the Common Agricultural Policy has on biodiversity, particularly through land-use intensification [4,5] and land abandonment [5,6]. In eastern and southern European countries, population declines have been slower due to less intensive agricultural activities as compared to Western Europe [8,9]. The effects of agricultural intensification and land abandonment on populations of farmland birds are largely unstudied in countries outside the EU, including Serbia, where their potential negative impacts are also thought to apply [10].

Protected areas are one of the oldest and most widely used means of conserving species and their habitats [11]. Farmland biodiversity poses a particular challenge for conservation activities based on protected areas [12] since farmland species inhabit areas primarily intended for human use. Declining farmland bird populations in the EU prompted a series of measures that were aimed at meeting the obligations of the EU Birds Directive (2009/147/CE). One such measure was establishment of the Natura 2000 network to preserve species and habitats listed under the Birds Directive and EU Habitats Directive (1992/43/EEC), which covers 22.2 million ha (10.6%) of the total agricultural land of EU members. Agri-environmental schemes (AES; [13]) were also established to improve biodiversity in agricultural areas, and they have been implemented to varying degrees in EU member states and with dif-

How to cite this article: Radišić D, Mišković M, Jovanović S, Nikolić T, Sekulić G, Vujić A, Milić D. Protected area networks are insufficient for the conservation of threatened farmland species: A case study on corncrake (*Crex crex*) and lesser grey shrike (*Lanius minor*) in Serbia. Arch Biol Sci. 2019;71(1):111-21.

ferent effects on bird populations within and outside of the protected areas [14,15].

Agricultural landscapes cover nearly 55% of Serbia [16] and harbor a rich biodiversity. Not being a member of the European Union, Serbia does not participate in the Natura 2000 network and does not apply any AES. Thus, the only realistic system of nature protection is through its network of national protected areas (NPAs) that include national parks, nature reserves, landscapes of outstanding features and natural monuments. Together, NPAs cover approximately 7% of Serbia [17]. Additionally, 42 important bird areas (IBAs), defined in 2009 based on the expert knowledge of professional and amateur ornithologists, encompass 14.5% of Serbian territory [18]. The proportion of agricultural habitats within the network of NPAs and IBAs (largely forests) is relatively small (14.5% and 24.9%, respectively). No scientific studies on the efficacy of NPAs or IBAs for farmland bird conservation have been conducted in Serbia, even though conservation of these species is of national and European importance [19]. Furthermore, although the significance of NPAs and IBAs for certain species has been evaluated, though solely on the basis of estimated population abundances [18], these analyses did not include spatially explicit information about the distributions of species or their suitable habitats.

Corncrake and lesser grey shrike are two threatened farmland species exhibiting population decline in much of Europe [20,21]. Population and population trends of both species in Serbia have been evaluated differently in recent decades [10,16,18,22]. Accurate distribution maps of corncrake and lesser grey shrike in Serbia do not exist due to lack of systematic large-scale surveys, preventing confident evaluations of the efficacy of protected areas for conserving them. Both species are listed in Annex I of the Birds Directive and in the national list of strictly protected species in Serbia (Code on declaration and protection of strictly protected and protected wild species of plants, animals and fungi, "Official Gazette of RS", no. 5/2010), which necessitates effective conservation. The aim of this study was to evaluate the amount of potentially occupied suitable habitats within the networks of NPAs and IBAs in Serbia. We combined field data and species distribution modelling to generate maps of suitable habitats and then conducted a gap analysis to assess the conservation status of habitats for both target species. Additionally, we wanted to produce spatially explicit recommendations for enlarging conservation networks in Serbia, representing areas with the greatest potential for habitat occupancy by both species. We believe that our research will facilitate conservation decisions and direct limited resources towards improving species protection in agricultural settings.

MATERIALS AND METHODS

Studied species

The corncrake is distributed throughout Europe and a significant part of central Asia [23]. It is a typical grassland species that breeds in different types of habitats with high and medium-high grasses, including steppes, peat bogs and hay meadows [24]. Their population has declined rapidly in Europe due to agricultural intensification and the disappearance of grassland habitats in farmland landscapes over the course of the 20th century [25]. Previously, the corncrake was considered globally threatened [23,26], but the species was down-listed because of large populations in its eastern range, whose sizes had been significantly underestimated due to insufficient research [27-29]. Increasing corncrake populations, attributed to changing agricultural practices, have been observed in Russia [27] and some other eastern European countries [30]. Conservation measures, including restoration and maintenance of habitats, are being successfully carried out throughout Europe [31]. In Serbia, the corncrake mainly inhabits hay meadows in hilly and mountainous areas [10], with a stable population estimated at 1240-1870 breeding pairs [16]. The distribution of corncrake in Serbia is thought to have changed during the 20th century, when the species began disappearing from the plains of the northern and central parts of the country [10,32].

The lesser grey shrike is a migratory passerine distributed throughout the Western Palearctic, where it inhabits steppes, forest-steppes and the Mediterranean zone [33]. It breeds in semi-open landscapes, including different agricultural habitats [34]. Nesting requires the existence of a group of trees or single trees, and habitat choice is affected by the presence of the structural elements this species uses to observe the terrain when hunting large insects and small vertebrates [35,36]. The largest populations are found in Russia, Turkey and Romania, but populations are declining in most European countries [21]. The population in Serbia is estimated at 730-1120 breeding pairs and is considered stable [16]. However, the population decreased in the second half of the 20th century, which is why it was considered quite rare during the early 2000s [22,32].

Description of the study area

Serbia is located in the central part of the Balkan Peninsula and covers an area of 88361 km^2. It has three major biogeographic regions: Continental, Pannonian and Alpine [37], and its complex relief, climate and geological history have resulted in a rich biodiversity [38]. Plains dominate the northern part of the country, whereas most of the land south of the Sava and Danube rivers is made up of hills and mountains. Forests cover 29.1% of the country's territory, mostly dominated by deciduous communities of oak and beech [39]. The majority of open habitats in Serbia are of anthropogenic origin, although there are preserved fragments of Pannonian steppe and alpine meadows. Agriculture is fairly intensive in the northern plains, with crop monocultures predominating. The landscape south of the Sava and Danube rivers is more heterogeneous, comprising cropland, meadows, orchards, hedges and small forests. Serbia is experiencing rural depopulation, as in most southeastern European countries, leading to changes in agricultural habitats such as transitioning of meadows and pastures towards shrub and forest.

In Serbia, NPAs are classified into seven categories according to national legislation ("Official Gazette of RS", no. 36/2009, 88/2010 and 91/2010 – corr. and 14/2016), with only a small proportion of these being strict nature reserves that preserve pristine habitats. The Serbian categories for protected areas are not equivalent to those of the International Union for Conservation of Nature (IUCN) [40]. Forests dominate in most Serbian NPAs. The Serbian IBA network was established during the 1980s, and it has been revised several times so that it now comprises 42 recognized by Birdlife International and five nationally important sites [18,41]. The IBA network is part of the "Ecological Network of Serbia" that unifies NPAs, IPAs (Important Plant Areas), PBAs (Prime Butterfly Areas), Ramsar sites, and other ecologically significant areas (Regulation on the ecological network, "Official Gazette of RS" no. 102/2010), and these areas are included in the Spatial Plan of the Republic of Serbia ("Official Gazette of the RS" no. 88/2010) [42].

Species occurrence data

We used published and unpublished data from professional and amateur ornithologists associated with the Bird Protection and Study Society of Serbia, collected between 2000 and 2014, to model the potential distributions of corncrake and lesser grey shrike. Most of the data for corncrake were obtained from an inventory published by Sekulić [10]. Only data from the two species' breeding periods were used, defined here as 1st May to 15th July. In most cases, precise coordinates of locations where individuals were seen or heard were recorded in the data. In a few other cases of published data where specific locations were not provided, we contacted the authors who kindly provided precise information. We excluded from our analysis the remaining records for which no precise locations could be obtained. We used a total of 302 lesser grey shrike records and 142 corncrake records. Only a few records from the Kosovo and Metohija area could be collected for the study period due to insufficient research. In order to avoid sampling bias, we have not used data from Kosovo and Metohija to build our model. However, we projected our model into Kosovo and Metohija, which allowed us to predict species distributions in that region and to evaluate local NPAs and IBAs.

Species distribution modelling

We modeled potential species distributions at a resolution of 1x1 km. Cell sizes of 1x1 km are larger than the home ranges of both species [36,43]. Three groups of variables considered to have an impact on species presence were used for modelling: climate, topography and land cover. All variables were resampled in a 1x1 km grid (WGS_1984_UTM_zone_34N) in ArcGis 10.1. program (©ESRI). Climate parameters were taken from the World Clim dataset [44]. In the first step, we selected climate variables considered to have biological significance for corncrake and lesser grey shrike (11 in total). We performed variance inflation factor (VIF) analysis to measure the collinearity among climate variables. Climate variables with high multicollinearity were removed until all remaining variables had VIF<10 [45], which resulted in us retaining four and five climatic variables for the corncrake and lesser grey shrike models, respectively (Table 1). The topographical variables of elevation and slope were derived from the Shuttle Radar Topography Mission (STRM) digital elevation model at a resolution of 250 m [46], so that we could calculate the mean height and mean slope of the terrain for each 1x1 km cell. Habitat variables were derived from the Coordination of Information on the Environment Land Cover (Corine Land Cover) map at a resolution of 100 m [47]. We chose six habitat types and calculated their areas in each 1x1 km cell (Table 1). Our habitat classification generally matched the second or third levels of the Corine classification, but we combined the Natural Grassland (3.2.1) and Pastures (2.4) categories due to their similarity and mosaic characteristics in Serbia, where large areas of grassland are occasionally mowed and sometimes extensively grazed.

We created our models of potential species distributions using MaxEnt (ver 3.3.4), a widely adopted approach that identifies the distribution closest to maximum entropy (closest to the uniform), subject to a set of constraints that represents spatial distribution of target species and environmental variables [48,49]. MaxEnt is a machine-learning tool that uses presence-only data and a set of background points [50]. For each of the predictors (environmental variables), Maxent derives a number of features (mathematical transformation of the predictors), and the mean of each feature closely matches the empirical average of the occurrence data [49,50]. Duplicate data (i.e. multiple findings from a single cell) were removed. We used the territory of Serbia as background and excluded Kosovo and Metohija since there are no

Table 1: Variables used for modelling of corncrake and lesser grey shrike distribution in Serbia with MaxEnt.

Variable	Corncrake			Lesser grey shrike		
	Contr.%	P.I.	Eff.	Contr.%	P.I.	Eff.
bio1 Annual Mean Temperature	10.9	26.1	-	2.3	6.4	+/-
bio2 Mean Diurnal Range (Mean of monthly (max temp - min temp))	7.1	7.5	-	1.9	5.5	+/-
bio5 Max Temperature of Warmest Month	Not included	/	/	1.6	3.8	+/-
bio8 Mean Temperature of Wettest Quarter	2.1	5.6	+/-	0.2	0.5	+
bio12 Annual Precipitation	3.8	5.6	+	27.1	30.4	-
elevation Average elevation of grid cell	35.2	12.2	+	4.6	3.8	-
slope Average slope of grid cell	0.9	1.7	+/-	12.9	6.7	-
forest Proportion of the grid cell covered with forest (clc 3.1)	21.3	21.3	-	36.6	33.3	-
grass Proportion of grid cell covered with grassland (clc 2.3 + 3.2.1)	1.2	0.4	+	9	3.3	+
intagr Proportion of grid cell covered with arable land (clc 2.1)	14.2	17.5	-	1.1	1.5	-
hetagr Proportion of grid cell covered with heterogeneous agricultural land (clc 2.4)	2.9	1.4	+	0.5	0.1	+/-
shrub Proportion of grid cell covered with transitional woodland scrub (clc 3.2.4)	0.4	0.6	+	0.9	3.1	-
urban proportion of grid cell covered with settlements (clc 1.1)	0.1	0.2	-	1.1	1.4	-

Contr.% – percentage contribution to the model; P.I. – permutation importance of the variable; Eff. – type of effect of variable on presence probability (+: positive, -: negative, +/-: quadratic) relevant data from this region for the study period. Ten thousand background points were automatically selected. Set features were linear, quadratic and hinge, and 15 replicates of cross-validation type were run. We used area under receiver-operator curve (AUC) values for model evaluation. Maps of the probability of species presence were translated into binary maps using the maximum training sensitivity plus specificity threshold [51], in which grid cells have a value of either 1 ("suitable") or 0 ("unsuitable").

Gap analysis

MaxEnt models are often used for gap analyses [12,52,53]. In order to conduct our gap analysis, we converted NPAs and IBAs into rasters at a resolution of 1x1 km. Cells were labeled as NPA or IBA if more than 50% of their surface area overlay either type of protected area network. Consequently, some extremely small areas of either type of network were not analyzed. The results of our gap analysis are presented as percentages of cells hosting suitable habitats located within an NPA or IBA (out of the total number of cells containing suitable habitat for each species). Also, we considered a scenario in which the NPAs and IBAs together formed an ecological network (NPA+IBA). Finally, we calculated the "gap" in protection of habitats suitable for both species for all three scenarios of protected areas (NPA, IBA or NPA+IBA).

RESULTS

Studied species distributions

Our species distribution models showed high discriminatory power for both modelled species, and can be described as 'good' [54]; the AUC was 0.8430 (+/-0.037) for the corncrake model and 0.872 (+/-0.043) for the lesser grey shrike model. Five and four variables contributed more than 5% of the descriptive power of the corncrake and lesser grey shrike models, respectively (Table 1). Both species were negatively affected by the proportion of forests ("forest"), arable land ("intagr") and settlements ("urban") within grid cells. The probability of lesser grey shrike presence decreased with increases in elevation and annual precipitation ("bio12"), whereas those variables had a positive effect on the probability of corncrake presence. As might be expected, the probability of presence for both species was positively affected by grassland area, which represents the main habitat for both species in eastern Europe [25,55-57].

Suitable habitats (probability of presence >0.282) for corncrake were found in 22.93% of the 1x1 km cells in Serbia (Table 2). Suitable habitats are located in mountainous and hilly areas throughout the country, with the highest concentration in the mountains of the eastern and western parts of Serbia (Fig. 1A, Fig. 1C). A relatively small number of suitable cells are also scattered throughout the northern plains.

Table 2. Number and percentage of grid cells suitable for corncrake, lesser grey shrike and for both species within the territory of Serbia and within the networks of protected areas. The percentage of the total number of suitable cells for species is shown in parentheses.

Species	Serbia	NPA	IBA	NPA+IBA
Corncrake	20274	2495 (12.31%)	5242 (25.86%)	5451 (26.89%)
Lesser grey shrike	16240	332 (2.04%)	1610 (9.91%)	1623 (9.99%)
Corncrake and Lesser grey shrike	1686	59 (3.5%)	267 (15.84%)	270 (16.01%)

NPA – network of nationally protected areas; IBA – network of important bird areas, NPA+IBA – two networks combined.

For lesser grey shrike, 18.37% of the cells in Serbia were designated as suitable (probability of presence >0.303). The highest concentration of suitable cells was located in the north of the country (Fig. 1B and C) where there are large tracts of continuous suitable habitat both in grasslands and cultivated land hosting the single trees, old orchards or hedgerows necessary for lesser grey shrike nesting [58]. South of the Sava and Danube rivers, suitable habitats were located in the valleys of large rivers and the foothills of mountains in the southern, central and eastern parts of the country, but lesser grey shrike is conspicuously absent from the west and southwest of Serbia.

The number of cells with habitat suitable for both species was 1686 (1.91% of the total number of cells in Serbia), and these were mostly located in eastern Serbia (Fig. 1C).

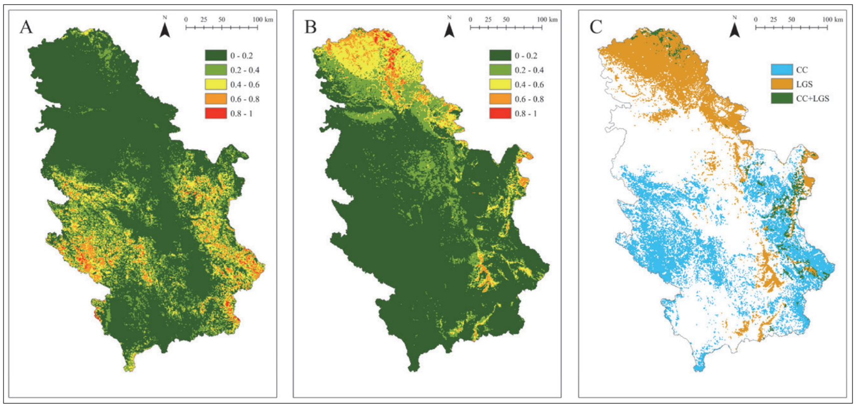

Fig.1. Distribution maps of corncrake and lesser grey shrike in Serbia obtained by MaxEnt. **A** – probability of presence of corncrake; **B** – probability of presence of lesser grey shrike; **C** – distribution of grid cells suitable for corncrake only (CC), lesser grey shrike only (LGS), and suitable for both species (CC+LGS).

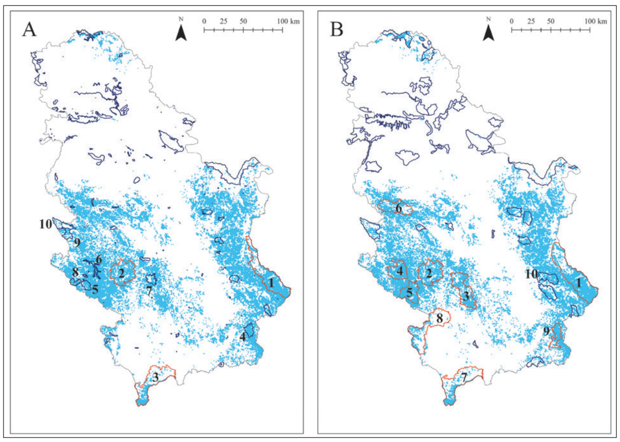

Fig.2. Distribution of suitable cells for corncrake with a map of: **A** – National Protected Areas (NPAs); **B** – Important Bird Areas (IBAs). Numbers indicate the ten NPAs and IBAs with the largest percentages of suitable cells for corncrake from Table 3. The borders of NPAs and IBAs with more than 1% of suitable cells for corncrake in Serbia are marked in red.

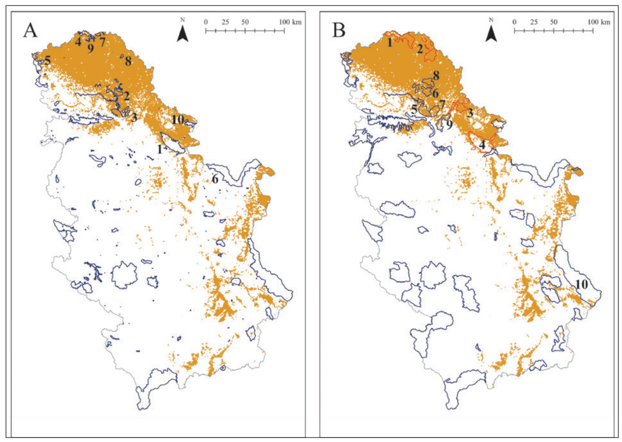

Fig.3. Distribution of suitable cells for lesser grey shrike with a map of: **A** – National Protected Areas (NPAs); **B** – Important Bird Areas (IBAs). Numbers indicate the ten NPAs and IBAs with the largest percentages of suitable cells for lesser grey shrike from Table 3. The borders of NPAs and IBAs with more than 1% of suitable cells for lesser grey shrike in Serbia are marked in red.

Table 3. List of the ten most important Nationally Protected Areas (NPAs) and Important Bird Areas (IBAs) for corncrake and lesser grey shrike in Serbia. The percentage of the total number of suitable cells for species is shown in parentheses.

NPA		IBA	
Corncrake	**Lesser grey shrike**	**Corncrake**	**Lesser grey shrike**
Stara Planina (3.9%)*	Deliblatska Peščara (0.4%)	Stara Planina (5.4%)*	Subotička Jezera and Pustare (1.4%)*
Golija (2.7%)*	Okanj Bara (0.4%)	Golija (2.7%)*	Pašnjaci velike droplje (1.2%)*
Šar Planina (1.6%)*	Carska Bara (0.2%)	Kopaonik (2.5%)*	Gornje Potamišje (1.1%)*
Vlasina (0.6%)	Subotička Peščara (0.2%)	Uvac and Mileševka (2.0%)*	Deliblatska Peščara (1.0%)*
Ozren-Jadovnik (0.4%)	Gornje Podunavlje (0.1%)	Pešter (2.0%)*	Titelski Breg (0.7%)
Uvac (0.3%)	Đerdap (0.1%)	Valjevske Planine (1.7%)*	Okanj-Rusanda (0.6%)
Kopaonik (0.3%)	Selevenjske Pustare (0.1%)	Šar Planina (1.7%)*	Carska Bara (0.6%)
Kamena Gora (0.3%)	Pašnjaci velike droplje (0.1%)	Prokletije (1.4%)*	Slano Kopovo (0.6%)
Šargan - Mokra Gora (0.3%)	Ludaško Jezero (0.1%)	Vlasina (1.0%)*	Srednje Potamišje (0.5%)
Tara (0.3%)	Mali Vršački Rit (0.1%)	Sićevačka Klisura (0.9%)	Stara Planina (0,4%)

* – site holds more than 1% of total suitable cells in Serbia for species

Gap analysis

The number of corncrake-suitable cells within NPAs accounted for 12.31% of the total number of cells with habitat suitable for the species, and this increased to 25.86% or 26.89% for the IBA or NPA+IBA networks, respectively (Table 2). Suitable cells were located in a total of 39 NPAs (Fig. 2A) or within 24 IBAs (Fig. 2B). More than 10 cells of suitable habitat occurred in 17 of these NPAs or in 21 IBAs. More than 1% of suitable cells could be found in three NPAs or in nine IBAs (Table 3, Fig. 2A, Fig. 2B). Our models of potential corncrake distribution indicate larger areas of suitable habitats within IBAs where breeding has previously been well documented (e.g. the IBAs "Stara Planina", "Uvac and Mileševka", and "Vlasina"), but also in areas with sparse records (e.g. IBA "Golija"). Large areas of suitable habitat for corncrake in eastern and southwestern Serbia are located outside the boundaries of NPAs and IBAs (Fig. 2A, Fig. 2B).

For lesser grey shrike, worryingly, there were only 2.04% of cells with suitable habitat for the species within NPAs (Table 2). These lesser grey shrike suitable cells were located in 23 different NPAs. Again, the percentage of lesser grey shrike-suitable cells increased within the IBA network (9.91%, 30 IBAs) and for our NPA+IBA network (9.99%) (Table 2). More than 10 cells of suitable habitats could be found in 10 NPAs and in 18 IBAs. No NPA contained more than 1% of suitable cells for lesser grey shrike, and only four IBAs met this criterion (Table 3, Fig. 3A, Fig. 3B). NPAs harboring slightly higher numbers of cells of suitable habitat are located in the northern parts of the country and represent typical Pannonian ecosystems that include fragments of steppe, salt pastures and meadows (Fig. 3A). South of the Sava and Danube rivers, suitable habitats for lesser grey shrike are located in the peripheral parts of several NPAs. Similarly, lesser grey shrike mainly inhabits the peripheries of IBAs that contain some agricultural habitats (Fig. 3B). Areas south of the Sava and Danube rivers with the highest density of suitable cells for this species (e.g. in the valleys of the Velika Morava, Južna Morava, Timok and Nišava rivers) are located outside the boundaries of NPAs and IBAs (Fig. 3A, Fig. 3B).

NPAs cover only 3.5% of the cells containing habitat suitable for both species, IBAs cover 15.84% and, combined, these networks cover 16.01% of the cells we predict to harbor suitable habitat for corncrake and lesser grey shrike (Table 2).

DISCUSSION

The species distribution modelling we used enabled us to identify patterns of corncrake and lesser grey shrike distribution in the absence of systematically-collected data from the field. Our results indicate relatively large areas of suitable habitat for both species in Serbia, which implies a somewhat larger national population than previously estimated. Nevertheless, population estimates based on habitat occupancy maps obtained by modelling have two limitations. First, occupancy patterns are shaped not only by abiotic environmental factors but also by biological interactions, dispersal, population dynamics and evolution [59], so all modelled locations deemed suitable may not necessarily be occupied. Second, uneven species distributions across a landscape limit the ability of habitat occupancy maps to predict local population abundances [60]. However, the probability of species presence obtained by species distribution models has been linked to abundances [61] or reproductive parameters [62]. Thus, it is reasonable to assume similar ratios for populations of species and amounts of suitable habitat within and outside NPAs and IBAs.

Our gap analysis indicates a very poor representation of suitable habitats for the studied species within NPAs, and representation of suitable habitat for the two species in IBAs differs significantly. NPAs in Serbia have been formed not only for the protection of species, but also for aesthetic, economic, historical and other reasons, so it is to be expected that a significant amount of habitats suitable for protected species lies outside their borders [53,63]. Furthermore, traditionally, forest and aquatic habitats are much better represented within NPAs, whereas agricultural habitats mostly lie outside or on their borders. Inclusion in NPAs of large areas of agricultural land, which are mostly privately owned, would present a major administrative and practical challenge in Serbia, explaining why there is such a low proportion of suitable habitats for farmland birds (such as our two target species of conservation concern) within NPAs. A similar situation is to be expected for other farmland species that share habitats with corncrake and lesser grey shrike (e.g. *Emberiza hortulana, Sylvia nisoria, Lanius collurio* and *Saxicola rubetra*). Notably, the mosaic agricultural landscapes of lowland plains suitable for lesser grey shrike are far less represented in NPAs than upland agricultural habitats. Non-intensively-used agricultural habitats suitable for corncrake are more represented within large NPAs in the mountains (e.g. Stara Planina, Šar Planina, Golija), where it was not possible to exclude these agricultural plots from the protection zones due to the complexity of the landscape. As in many European countries, lowland farmland species in Serbia are significantly less well protected relative to upland species [12,64].

Unlike NPAs that are defined by criteria other than simply species protection, IBAs are defined with the clear objective of preserving populations of native bird species and all of the criteria used to delineate them are based on quantitative parameters for species of conservation concern [41]. IBAs in Serbia are considered potential future "Special Protected Areas" (SPAs) as part of the Natura 2000 network [18]. For lesser grey shrike, the proportion of the population within IBAs is very low (less than 10%) and is probably insufficient to protect the species. This clear lack of representation of suitable habitats for lesser grey shrike within the IBA network may pose a serious obstacle to the conservation of this species, since the Natura 2000 network is recognized as the most important mechanism for lesser grey shrike conservation in some EU countries [57]. Our results highlight the need to define new IBAs (or SPAs within the Natura 2000 network) and for expansion of existing ones so that habitats important to lowland farmland species, such as lesser grey shrike, can be better represented. The lesser grey shrike is particularly dependent on grassland habitats and most of the occurrence data originates from areas with fragments of steppe, salt meadows or pastures. Inclusion of larger areas of these semi-natural habitats in NPAs and IBAs would contribute greatly to the conservation of a significant portion of the Serbian lesser grey shrike population. The situation for corncrake is somewhat different. IBAs cover about 1/3 of suitable habitats for this species, partially due to there being better knowledge of its distribution, but also because large IBAs in Serbia were actually created as major extensions into zones around existing and relatively well-researched mountain NPAs. Similar ratios of corncrake pair numbers within and outside the boundaries of IBAs have been estimated [18]. In Serbia, not a single IBA has been designed to encompass only agricultural habitats. Instead, they are typically sited at the edges of protected forest, alpine or wetland zones. Consequently, many valuable heterogeneous farmland landscapes, which do not have well-preserved natural habitats in their vicinity, are not recognized as IBAs. Most of the cells designated as containing suitable habitats for both analyzed species lie outside IBAs, and we expect that these locations also support a high diversity of other farmland birds.

Expansions of existing NPAs and IBAs in western Serbia (i.e. the areas of Ozren-Jadovnik, Zlatibor, Uvac and Mileševka, Pešter), and establishing new ones in the eastern part of the country (e.g. Svrljiške Planine, Vidlič, Ozren, Devica, Dubašnica, Homoljske Planine, Kučajske Planine) would contribute significantly to the conservation of habitats suitable for corncrake. For lesser grey shrike, completely new NPAs and IBAs should be defined in eastern Serbia (in the surroundings of Negotin, Kladovo, Žagubica and in the Timok and Nišava river valleys), as well as in the lowland valleys of the Velika and Južna Morava rivers. Improvements to the conservation status of very fragmented grassland habitats suitable for lesser grey shrike in northern Serbia will require both establishment of new NPAs and IBAs, as well as the enlargement of some existing ones (e.g. Pašnjaci velike droplje, Okanj-Rusanda, Slano Kopovo).

Conservation into the future of a large proportion of the populations of both analyzed species will depend on the management of agricultural habitats outside of protected networks. Protection of farmland species in the EU is partially based on AES, albeit with mixed success, which includes a financial mechanism for managing farmland bird habitats both within and outside protected networks [15,65]. Both corncrake and lesser grey shrike are target species for AES in some EU countries [31,66]. In Serbia, efforts for habitat management to maintain characteristics that target species survival are largely restricted to within protected networks, at least until Serbia develops functional AES. Although there is a legal basis for the protection of habitats of strictly protected species located outside protected networks, it is hard to enforce these measures in practice. National professional expert institutions supervise habitat management in NPAs in Serbia, so the likelihood for implementation of appropriate measures in them is largely better. Therefore, the only long-term mechanism for conserving species such as corncrake and lesser grey shrike is through the creation of a functional network of protected areas in Serbia (particularly Natura 2000 areas, which are focused on species and habitat conservation). It is important to note that even in protected areas, the management of habitats for strictly protected species is often inadequate, sometimes due to a lack of fundamental information about species distributions or their habitat requirements. Our spatially explicit modelling results represent a significant contribution to knowledge about the distribution of suitable habitats for corncrake and lesser grey shrike, both within and outside of protected networks. Our identification of large areas of suitable habitat enables allocation of management efforts to good candidate localities, even in very poorly investigated areas.

We acknowledge that the distribution of suitable habitats for corncrake and lesser grey shrike is likely to be significantly altered in the future due to climate change and changing land use [57], so changes in species' distribution and abundance should be carefully monitored. Serbia is not a member of the EU so it still does not implement the Common Agricultural Policy, but the agricultural intensification associated with this policy is a continent-wide trend that has been identified as the most important factor leading to reduced farmland biodiversity in Europe [7]. Populations of farmland birds are widely used indicators of the declining biodiversity associated with agricultural land in Europe [67], which is why more detailed studies are needed to determine the abundances and population trends of threatened species, and population monitoring is necessary to understand their responses to the complex processes of land use and climate change and ecosystem succession in Serbia. Considering the lack of systematically collected data in Serbia, spatially explicit maps of suitable habitats of species could be a useful tool for developing monitoring schemes and conservation strategies for farmland biodiversity, both within the boundaries of protected area networks and beyond them.

Funding: This work was financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. OI 173002, "Conservation strategy for protected and strictly protected hoverflies (Insecta: Diptera: Syrphidae) species in Serbia – Case study") and the Provincial Secretariat for Science and Technological Development (Grant No. 142-451-2591/2017: "Evaluation of Ecological Networks in AP Vojvodina as support for nature conservation").

Acknowledgements: The authors are sincerely grateful to all professional and amateur ornithologists from the Bird Protection and Study Society of Serbia who kindly provided data on corncrake and lesser grey shrike distribution. Special appreciation is extended to Marija Miličić who helped us in the analysis of environmental variables used for species distribution modelling and to John O'Brien for proofreading the English version of the manuscript.

Author contributions: DR, GS and SJ participated in collecting data on corncrake and lesser grey shrike in the field. GS and MM prepared the database on corncrake distribution. SJ prepared the database on lesser grey shrike distribution. DR, MM, SJ, TN and DM performed the species distribution modelling with MaxEnt. Gap analysis was performed by DR, TN and DM. The interpretation of the results was done and approved by all authors. DR, MM, SJ and TN wrote the manuscript. AV and DM supervised the activities and reviewed several drafts of the manuscript.

Conflict of interest disclosure: The authors state that this manuscript has not been published before and is not under consideration for publication anywhere else. Publication of this article was approved by all authors.

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