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Scale dependence of landscape-structure-based estimation of abundance of Eurasian skylark (*Alauda arvensis*)

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ABSTRACT

The habitat and occurrence of farmland birds are strongly determined by the agricultural-landscape structure. Changes in land cover composition and configuration are one of the main causes of the significant decline in abundance of the Eurasian skylark (*Alauda arvensis*) in recent decades. This farmland-bird species is common in agricultural areas of Eurasia. In this study we investigate the land use factors involved in the decline in Central Europe, Hungary. We used two different land use/land cover (LULC) datasets, which were compiled at different scales: the Ecosystem Map of Hungary (EMH), a very precise LULC map based on a 0.04-ha minimum mapping unit, and the Corine Land cover (CLC) dataset, built using a 25-ha minimum mapping unit. We studied the impact of landscape composition and configuration on skylark abundance by using negative-binomial generalized linear models. After identifying skylark preferences among LULC categories at different scales, we calculated the EMH and CLC dataset-based landscape indices (such as mean patch size and mean fractal dimension index) of the skylark preferred (arable lands, pastures, grasslands and meadows) and the nonpreferred (artificial surfaces, forests, complex cultivation patterns and waters) LULC classes. Then we compared the results with field observations of skylark abundance in the database of Hungarian Common Bird Monitoring (MMM). On the basis of statistical analysis of connections between the landscape indices and the skylark-abundance data, we estimated skylark abundance for those areas where the skylark-abundance datasets from field observation were not available. We also tested the estimates by assessing model sensitivity when we input different-scale LULC data and used different observation windows (grain size). Our statistical model using EMH dataset explained 41.22% variance of the skylark abundance data, while the rest, 58.78% of variance is not accounted by the model presumably due to local environmental factors not considered in our model. The regional scale (CLC-based) estimation of skylark abundance yielded significantly lower accuracies (33.76% in 1200 m radius buffer zones and 34.11% in 600 m radius buffer zones). We conclude that the size of the landscape windows (grain size) land cover has a significant impact on the relationship between skylark and landscape structure. Our results can help to test the usefulness and limitations of the different-scale LULC databases and to find the optimal grain size for modelling and estimating farmland-bird abundance data and may support landscape scale conservation management plans.

1. Introduction

Landscape composition and the configuration of land cover patches (mapped and delineated land cover units) determine the occurrence of farmland birds (Berg et al., 2015; Gottschalk et al., 2010). The skylark is one of the most characteristic farmland birds of European cultural landscapes (Donald 2010) with an Unfavourable Conservation Status (Petersen 2007). The ongoing decline of the abundance of the Eurasian skylark (*Alauda arvensis*) observed in recent decades is due to changes in the structure of the landscape (spatial distribution, size, and shape of land use/land cover (LULC) patches) in addition to agricultural intensification (Berg et al., 2015; Tryjanowski et al., 2011). Agriculture, including arable land, is the most dominant LULC category globally, particularly in European terrestrial ecosystems (EBCC, 2015).

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Differences in heterogeneity and spatial structure of LULC patches across rural areas impact farmland-bird diversity (Morelli et al., 2020; Toth et al., 2020). It is essential to identify the composition and the configuration of the landscape preferred by birds to plan the land use of protected areas. As land cover databases are currently available at the increasingly detailed resolution, many studies estimate abundance and diversity of agricultural avifauna with high precision based on spatial characteristics of LULC types, i.e., landscape composition and configuration (Gottschalk et al., 2010; Hoffmann et al., 2016, 2018). These studies have found a link between the intensity of agricultural production, crop heterogeneity, and the abundance of farmland birds. However, the majority of prior studies examined populations of the Eurasian skylark only on a local scale (point based assessment) (Miguet et al., 2013; Sauerbrei et al., 2014; Schlager et al., 2020) while landscape structure studies are scarce. Size and shape characteristics and land cover heterogeneity of different LULC patches may also be critical for preserving farmland-bird species. Thus, it is important to reveal the effectiveness of land cover databases that use different resolutions (scales) for estimating the abundance or density of skylarks. The selection of a suitable scale of LULC data and the optimal size of the landscape window (grain size) are important characteristics in the habitat-based estimation of bird fauna and for effective landscape conservation planning (Buyantuyev and Wu, 2007; Reif et al., 2008; Šímová and Gdulová, 2012; Uuemaa et al., 2005; Wu, 2004).

In this study, we investigated the effect of landscape composition and configuration on the abundance of the Eurasian skylark, a widespread species in agricultural areas of Eurasia that has been declining significantly in recent decades in Hungary (Szép et al. 2021). We used land cover data obtained at different spatial resolution to test the applicability of different scales of land cover databases for estimating farmland-bird populations. We used a very high-resolution LULC map: the Ecosystem Map of Hungary (EMH) (Agrárminisztérium, 2019, Tanács et al. 2021) and the Corine Land cover (CLC) dataset to described the structure of rural landscapes. Comparing skylark abundance data with the EMH and CLC land cover datasets, we identified skylarks' preferred areas (habitats) and nonpreferred areas at different scales (Szilassi et al., 2019). Landscape indices are frequently used as proxies for biodiversity and habitat change, according to the pattern and process paradigm, which examines the relationship between landscape patterns, spatial distribution, and landscape processes (Borges et al., 2017; Csikós and Szilassi, 2021; Csorba and Szabó, 2012; Radović et al., 2011; Radović and Tepić, 2009; Szilassi et al., 2017; Uuemaa et al., 2013, 2009; Walz, 2011)..

The main aims of our research were the following:

- Determine skylark land cover preferences, preferred and non-preferred LULC classes by using two LULC datasets at different resolutions (scales).
- Assess the influence of total areas of different land cover classes (landscape composition), and shape and size characteristics of LULC patches (landscape configuration) at different grain size or scales (radial buffer zones from observation points) in Hungary.
- Analyse the scale dependence of the relationship between skylark abundance and landscape structure and identify best grain size (landscape window) for modeling skylark abundance.

We tested the usefulness of the regional (continental) scale LULC databases for estimating this farmland-bird abundance. Our results also added useful information for landscape planning in protected areas and identified LULC composition and configuration optimal for the skylark. Furthermore, based on our results, the proper combination of land cover datasets scale and grain size can be chosen for the estimation of skylark abundance.

2. Material and methods

2.1. Study area

Hungary is part of the Pannonian biogeographical region and is located in Central Europe's Carpathian Basin (Lat 45°43′ to 48°35′N, Long 16°06′ to 22°53′E) (Fig. 1). The overall area is 93,033 km^2, with elevations ranging within 77–1014 m above sea level. Agricultural land is the dominant land use category, accounting for 61% of the country's total area (Farkas and Lennert, 2015). The remaining land cover consists of 5.5% artificial surface, 20.7% cultivated as meadows and woodland, and 12.8% other categories.

2.2. Databases

2.2.1. Land use/land cover maps

We applied a very high resolution, local-scale EMH map, which is in the form of a digital LULC database for the entire country of Hungary (Agrárminisztérium, 2019; Tanács et al., 2021). It was based mainly on mapping in 2015, and LULC maps from the European Copernicus Program (such as the Urban Atlas), CLC (including high-resolution layer), and Sentinel-2 satellite images were also used for validation and creation of this dataset. The dataset comprises three hierarchical levels of LULC categories at a resolution of 20 × 20 m (the minimum mapping unit). Level 1 has six lower-level LULC subclasses, Level 2 has 22 subclasses, and Level 3 has 56 subclasses. We used the second-level LULC classes (22) for our analysis, but these LULC classes were aggregated into seven classes to reduce the number and the likelihood of correlation among them (Table 1).

We also used the CLC regional-scale LULC database for our investigations. The European CLC maps were created at a regional scale, using the same methodology and nomenclature, to detect land cover changes in most European countries (EEA, 2006; EEA and ETC-TE, 2017). The digital LULC maps are available at 1:100,000 scale with a 25 ha minimum mapping unit for land cover patches and a 100 m minimum width for linear landscape components. Three land cover assessments have been provided since 1990, because mapping is performed to update the data every six years. There are 44 CLC land cover and land use classes in Europe, 28 of which apply to Hungary (EEA and ETC-TE, 2017) and there were 21 CLC LULC categories within the study area. We used the CLC Level 2 land cover classes, which were aggregated into the same thematic groups applied to data from the EMH database (Table 1). We used the CLC 2018 dataset for our analyses, which was mapped based on 2015 satellite images (Gudmann et al., 2020; Kosztra et al., 2019). Estimated proportions of land cover types based on EMH and CLC on our study sites (600 m buffer zones of bird monitoring points) are compared in Table 2. Other authors showed that landscape composition and land cover types have the greatest impact on the abundance of this species within this radius, so a 600 m buffer zone was chosen (Engel et al., 2012; Miguet et al., 2013; Szilassi et al., 2019).

The EMH and CLC databases used in this study are suitable for testing the scale sensitivity of the connections between the different land cover configurations and the skylark-abundance data. Fig. 2 shows that the EMH database is more detailed and has more linear elements. The CLC database presents larger polygons in a generalised way.

For identification of the skylark preferred and nonpreferred LULC classes, we calculated the total areas of the main (aggregated, Table 1) LULC classes of the CLC and EMH databases.In each MMM points landscape composition and structure was extracted in 300, 600 and 1200 m for further analysis.

2.2.2. Eurasian skylark-abundance data

In Hungary, a country-wide bird-monitoring survey has been conducted every year since 1999 by ~ 800 field surveyors. Their field observations led to the establishment of the Mindennapi Madaraink Monitoringja (MMM, Hungarian Common Bird Monitoring)), based on

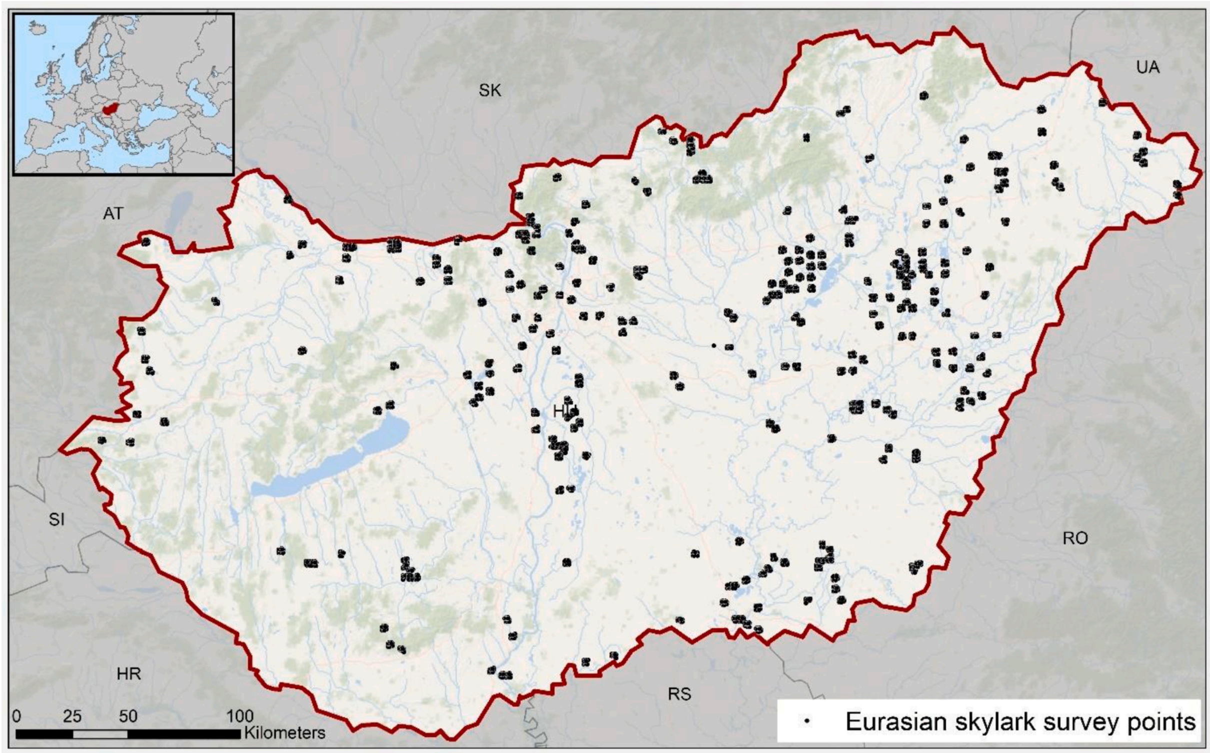

Fig. 1. Spatial distribution of 4476 Eurasian skylark survey points in Hungary, where skylark population was counted during 2015–2018 bird-monitoring survey (Data source: Hungarian Common Bird Monitoring, MMM (Szép and Nagy, 2001)).

semirandom sampling design and standard double point count method (Szép and Gibbson, 2000; Szép and Nagy, 2001; Szép et al., 2012). We analyzed the skylark-abundance datasets collected from the 4476 MMM field-observation points across Hungary during 2015–2018 (Appendix 1). In cases when multiple-year data were available at one point, the average of them has been used. At each location, within a 100 m observation radius, the observers conducted point counts through two spring sessions with at least two weeks break between samplings, from mid-April to mid-June. Counting was completed between 5:00 and 10:00 AM when the wind speed was < 5 m/s, and there was no rain. The minimum distance among the surveyed observation points was 500 m. The yearly highest number of birds observed was recorded for each observation point.

2.2.3. *Landscape metrics*

We used EMH and CLC data to calculate size- and shape-related landscape parameters. Using the V-LATE 2.0 extension of Arc GIS 10.3 software, we first calculated patch-level landscape LULC indices for each LULC patches (polygons) of EMH and CLC data, such as the size and shape characteristics of individual LULC patches, the primary computational basis for developing a landscape metric. LULC patches were delineated based on the analysis of satellite imagery using automatic image analysis techniques in both (EMH and CLC) databases. We determined patch size (PS), which is the total area of a given LULC patch; furthermore, we calculated the fractal dimension (FRACT) metric that describes the shape complexity of LULC patches (Table 3).

We identified as "skylark preferred" classes those LULC types, which showed positive relationships with the MMM abundance datasets. In contrast "skylark non-preferred" were the LULC categories that showed negative relationships with the MMM abundance datasets. Average values of these landscape metrics were calculated for all preferred and non-preferred LULC polygon classes within each buffer zones to compare their values with the skylark abundance data (i.e. PS for polygon sizes and FRACT for shapes). If we intersected the circles of the buffer zones with the LULC polygons, the shape and size of the polygons would have been deformed and, consequently, their descriptive landscape metrics would have changed. Therefore, we did not intersect the circle buffer zones with the LULC polygons. An LULC polygonwas considered for the average calculations if its centroidwas located within the given buffer zone. Consequently, the total area of the polygons under consideration differed from the whole area of the given buffer zone (circle). Therefore, in the case of the skylark preferred and non-preferred LULC groups (classes), the landscape metrics of patches within the buffer zones were averaged using the area weighted mean method, based on the following equation (Botequilha de Carvalho Leitão et al., 2006):

$$AWM_{LI} = \sum_{i=1}^{n}\left[LI_{ij}\left(\frac{a_{ij}}{\sum_{j=1}^{n}a_{ij}}\right)\right]$$

, where LI_{ji} is a landscape index (PS or FRACT) of the j^{th} patch, in the i^{th} class (preferred or nonpreferred LULC groups), a_{ij} is the area of the j^{th} patch, in the i^{th} class (preferred or nonpreferred LULC groups), and n is number of LULC patches inside a given circle radius buffer zone (assuming $n > 0$).

We used the Geospatial Modelling Environment (GME) tool of ArcGIS 10.3 to calculate the area-weighted mean values of the skylark preferred and non-preferred LULC polygons for each investigated buffer zones (Beyer, 2021).

We compared the AWMPS and AWMFRACT landscape indices of the skylark-preferred and non-preferred LULC classes with the skylark-abundance data within the 300 m-, 600 m-, and 1200 m-radii buffer zones (28.27 ha, 113.09 ha, and 452.38 ha landscape windows, respectively) surrounding the MMM bird observation points.

2.3. *Statistical analysis*

To understand the relationship between LULC types and skylark abundance, we first identified the LULC categories favoured (used as habitat) by skylarks versus those not preferred by this species. The arable-land LULC category was excluded from the first part of the statistical analysis (habitat type identification), because in European

Table 1
Aggregated main land use/land cover (LULC) classes used in Corine Land Cover (CLC) and Ecosystem Map of Hungary (EMH) databases.

Corine Land Cover database nomenclature LULC class in CLC database	CLC code	Aggregated LULC classes in this study	Ecosystem Map of Hungary database nomenclature EMH code	LULC class in EMH database
Continuous urban fabric	111	Artificial surfaces	111	Low buildings
Discontinuous urban fabric	112		112	High buildings
Industrial or commercial units	121		121	Paved roads
Road and rail networks and associated land	122		122	Dirt roads
Port areas	123		123	Railways
Airports	124			not exist
Mineral-extraction sites	131		131	Other paved or unpaved artificial areas
Dump sites	132			not exist
Construction sites	133			not exist
Green urban areas	141		141	Green urban areas with trees
Sport and leisure facilities	142		142	Green urban areas without trees
Non-irrigated arable land	211	Arable lands	210	Arable land (2100)
Vineyards	221	Vineyards	221	Vineyards (2210)
Fruit trees and berry plantations	222	Fruit/berry, and other plantations	222	Fruit/berry and other plantations
Annual crops associated with permanent crops	241	Complex cultivation patterns	231	Complex cultivation patterns with scattered buildings
Complex cultivation patterns	242		232	Complex cultivation patterns without buildings
not exist		Pastures grasslands and meadows	311	Open sand steppes
not exist			312	Closed sand steppes
not exist			320	Salt steppes and meadows
Pastures	231		331	Calcareous open rocky grasslands
Natural grasslands	321		332	Siliceous open rocky grasslands
not exist			340	Closed grasslands in hills or on cohesive soil
not exist			350	Other herbaceous vegetation
not exist		Forests	410	Forests without excess water
Broad-leaved forest	311		420	Natural riverine forests
Coniferous forest	312		430	Other forests with excess water
Mixed forest	313		440	Plantations
not exist			450	Non-wooded areas registered as forests or under reforestation
Transitional woodland–shrub	324		460	Other ligneous vegetation, woodlands
Inland marshes	411	Marshlands	511	Tall-herb vegetation of marshes and fens standing in water
Peat bogs	412		512	Fens and mesotrophic wet meadows, with periodic water
			520	Swamp woodlands
Watercourses	511	Watercourses	620	Watercourses
Waterbodies	512	Waterbodies	610	Waterbodies

Table 2
Proportion of land cover types inside 600-m-radius buffer zone of 4476-bird-monitoring observation points, based on Corine Land Cover and Ecosystem Map of Hungary data.

Land cover type	Corine Land Cover		Ecosystem Map of Hungary	
	Area (%*)	Observation points (%**)	Area (%*)	Observation points (%**)
Artificial surfaces	8.85	29.3	11.53	72.9
Arable lands	47.57	79.1	44.78	82.8
Vineyards	0.14	1.1	0.27	2.6
Fruit and berry plantation	0.48	2.2	0.67	14.9
Complex cultivation	4.32	21.6	1.92	17.7
Pastures, grasslands and meadows	21.56	53.1	20.76	88.6
Forests	14.25	36.4	16.13	77.9
Marshlands	0.94	6.7	3.85	10.1
Watercourses	0.59	3.2	0.63	8.8
Waterbodies	0.98	5.1	0.68	8.4

*where 100% is total area of 4476 bird-monitoring observation points within 600-m-radius buffer zones.
**where 100% is total number of 4476 bird-monitoring observation points.

countries agricultural land is the landscape matrix (dominant LULC type in the landscape), so the proportion of this category shows strong correlations with other LULC types. Furthermore, it is well-known that skylark have a strong preference for agricultural fields and benefit from relatively large fields (Gayer et al., 2019). We used generalized linear models (GLMs) to determine the impact of land cover on skylark abundance. We tested the overdispersion of skylark-abundance data by applying the "*overdispersiontest*" function in applied econometrics package in R (*AER* package) (Kleiber and Zeileis, 2008) and we applied negative-binomial models (link = log) to account for the observed overdispersion. We generated models using all possible combinations of explanatory variables (LULC categories) and calculated Akaike's information criterion to rank them with the dredge function of the *MuMin* package in R (Barton, 2015). We used model averaging for competitive models (delta AICc < 2) to address uncertainty arising from the high number of candidate models (Burnham and Anderson, 2002). The significance of the variables was estimated by the *LmerTest* package (Kuznetsova et al., 2020). On the basis of GLM results, we constructed two groups of land cover types from the EMH LULC categories preferred (significant positive relation) and nonpreferred (significant negative relation). We then analyzed the relationship between the landscape metrics of the preferred land cover (as habitats) and the nonpreferred land cover.

We used skylark-abundance data as response variable and total areas of skylark preferred (arable land included) and nonpreferred LULC types, furthermore, the shape and size-related landscape indices (AWMPS and AWMFRACT) of the skylark preferred (arable land included) and nonpreferred LULC types as explanatory variables. We used negative binominal GLM and model averaging to assess the relationship between skylark-abundance data and the grouped land cover data. Next, we analyzed the shape and size characteristics of the LULC types that showed a significant positive correlation with skylark abundance. We ran separate models for each buffer size (i.e. 300 m, 600 m and 1200 m radius buffers). The variables were in different dimensions, therefore we transformed the variables into values between 0 and 1.

We built up a training and a testing data sets from the data of the 4476 observation points (66.6 percent and 33.3 percent of the study areas, respectively). We used random sampling (*sample.split* function from *caTools 1.18* package (Tuszynski, 2021)). We ran the GLM on the training group to create an equation then based on the equation we estimated the skylark abundance on the test group. The estimated skylark-abundance data was calculated from the training data set by using the *predict* function of the car package (Fox and Weisberg, 2019).

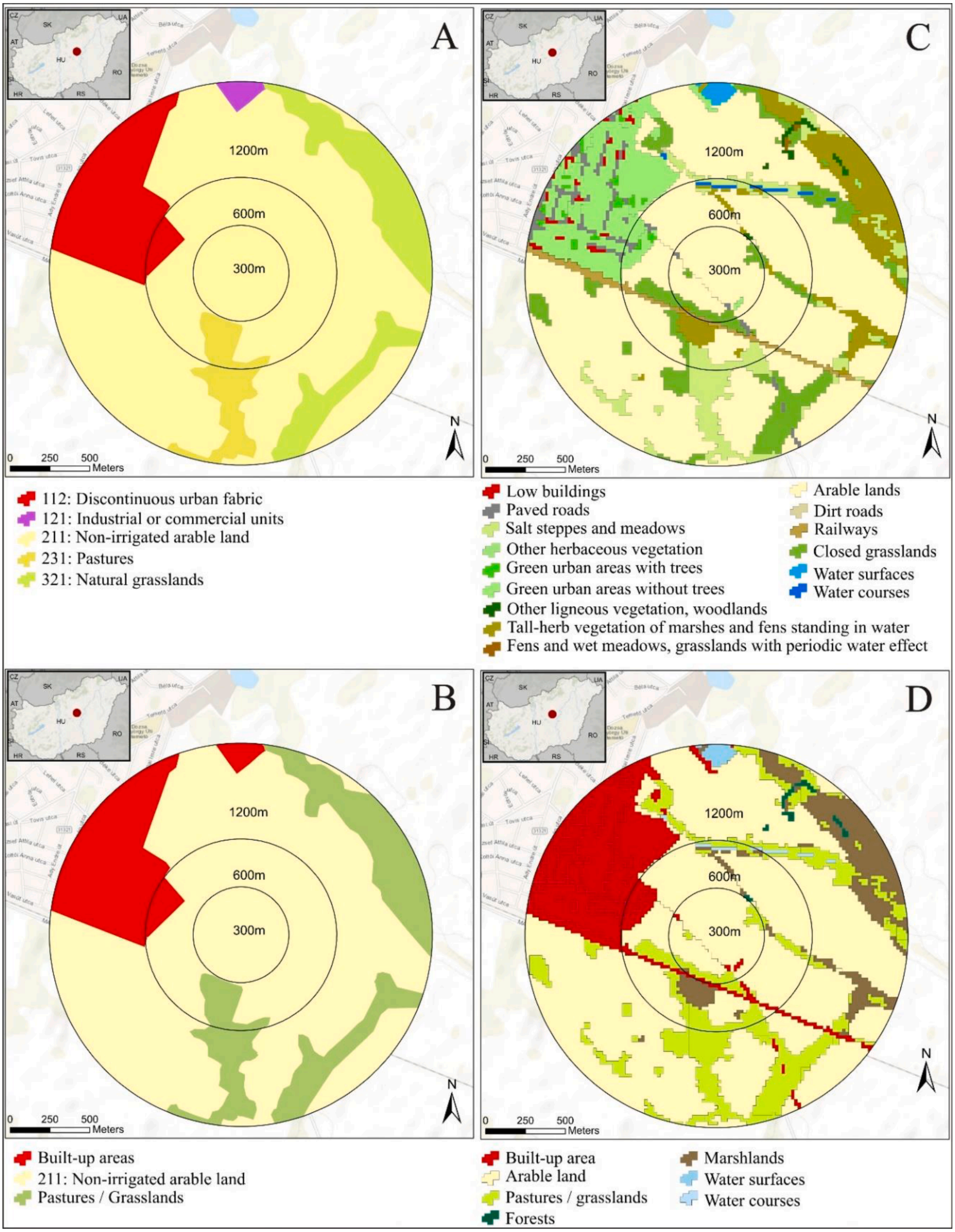

Fig. 2. Examples of land use/land cover (LULC) maps at different resolutions and based on Ecosystem Map of Hungary (EMH) and Corine Land Cover (CLC) datasets at different grain size (different buffer zones surrounding bird-monitoring observation points: 300-m, 600-m, and 1200-m radii). (A) All CLC LULC classes; (B) Aggregated CLC LULC classes; (C) All EMH LULC classes; (D) Aggregated EMH LULC classes.

We used Spearman's rank correlation to show the correlation between the testing dataset and estimated values (Kendall, 1994; Upton and Cook, 2014).

3. Results

We selected LULC classes that showed a significant statistical relationship (negative or positive) with the skylark-abundance data from the CLC and EMH LULC categories (Table 4). We found similar results for

Table 3
Descriptions and calculations of applied landscape indices (Blaschke, 2006; Forman, 1995; Uuemaa et al., 2013).

Structural feature	Index	Name and description	Calculation
Size- and shape-related landscape metrics	PS	Patch Size is computed by the total area of a given LULC patch.	$PS = a_{ij}$ where a_{ij} is area of j[th] LULC patch, in i[th] class
	FRACT	Fractal Dimension Index is two times logarithm of patch perimeter (m) divided by logarithm of patch area (m^2).	$FRACT = \frac{2\ln p_{aij}}{\ln a_{ij}}$, where p_{aij} is perimeter of j[th] LULC patch, in i[th] class a_{ij} is area of j[th] LULC patch, in i[th] class a

Table 4
Statistical relationship between total areas of aggregated LULC classes of Ecosystem Map of Hungary and Corine Land cover data, with skylark-abundance data within 600-m-radius buffer zone from MMM observation points, based on GLM results after model-averaging [GLM, generalized linear model; EMHEMH, Ecosystem Map of Hungary; LULC, land use/land cover; MMM, Hungarian Common Bird-Monitoring Database; N.S., not significant correlation].

GLM test relationship between aggregated LULC classes of CLC database and skylark-abundance data (coefficient values)	**Aggregated LULC class**	GLM test relationship between aggregated LULC classes of EMH database and skylark-abundance data (coefficient value)
Preferred Land cover Types		
0.0115 ($p < 0.001$)	Pastures grasslands and meadows	0.0100 ($p < 0.001$)
Neutral Land cover Types		
(N.S.)	Vineyards	(N.S.)
(N.S.)	Fruit and berry plantations	(N.S.)
Nonpreferred Land cover Types		
−0.0517 ($p < 0.001$)	Complex cultivation patterns	−0.0191 ($p < 0.001$)
−0.0332 ($p < 0.001$)	Artificial surfaces	−0.0419 ($p < 0.001$)
−0.0330 ($p < 0.001$)	Forests	−0.0302 ($p < 0.001$)
−0.0113 ($p < 0.001$)	Marshlands	−0.0138 ($p < 0.001$)
−0.0654 ($p < 0.001$)	Watercourses	−0.0501 ($p < 0.001$)
−0.0170 ($p < 0.001$)	Waterbodies	−0.0137 ($p < 0.001$)

the two different-scale LULC maps. Besides arable fields, the preferred habitats of the skylark were meadow, pasture, and grassland LULC classes. Artificial land, water, forest, and swamp land-cover classes showed a significant negative relationship with skylark-abundance data. Therefore, we considered them to be nonpreferred land cover categories. We considered vineyard, fruit, and berry plantation as neutral LULC types in both CLC and EMH databases, as these categories did not significantly correlate with skylark-abundance data (Table 4). Inside the three investigated grain sizes, the MFRACT have a positive relation with preferred LULC (both on EMH and CLC), whereas there was a negative relationship with nonpreferred habitats both on EMH and CEC.

Our results showed that the scale and resolution of the land cover map datasets and the size of the landscape windows (grain size) significantly affected the relationship between skylark and landscape structure (Table 5). In most cases, significant statistical relation was observed between the skylark-abundance data, the summarized total areas, and configurations of the skylark habitat (preferred) and nonpreferred LULC patches. It is notable that only the area-weighted mean patch size (AWMPS) of the skylark-nonpreferred LULC patches did not show a significant relation with skylark-abundance data within the 300-m- and 600-m-radii buffer zones in the high-resolution (EMH) land cover map data. The AWMPS of the preferred LULC patches did not show a significant statistical relationship with the skylark-abundance data only within the 1200-m-radius buffer zone in the local-scale EMH dataset. The area of the preferred LULC classes shows negative relation inside the 300-m- and 1200-m-radii buffers from the MMM observation points.

The Area Weighted Mean Fractal Dimension Index (AWMFRACT) and Area Weighted mean patch Size (AWMPS) landscape metrics calculated from the regional-scale CLC data showed similar significant relations with the skylark-abundance data with the same sign (either negative or positive) as the AWMFRACT and AWMPS landscape metrics for the local-scale EMH database. However, for the AWMPS parameter describing patch area of preferred and nonpreferred LULC types, we observed a difference in the sign of the correlation between the two different scales of land cover databases and the skylark abundance data. The area and AWMFRACT metric values of the nonpreferred CLC LULC patches show a stronger negative relation with skylark-abundance data than for the EMH database. This relationship holds for all the investigated buffer zones (300-m, 600-m, and 1200-m radii). The preferred land cover types derived from local-scale EMH data related stronger with skylark-abundance data than types derived from regional-scale CLC data within the 300 m- and 600 m radii buffer zones.

From our results (Table 6), we derived equations that describe and estimate skylark population in a given landscape. The most-accurate one based on the EMH dataset (in the 300-m-radius buffer zone) is.

$$Skylark_{pop} = -1.26 + 1.1{*}Area_p - 2.06{*}Area_{np} + 0.79{*}MPS_p + 1.95{*}MFRACT_p - 0.34{*}MFRACT_{np}$$

and the most-accurate one based on the CLC dataset (in the 1200-m buffer zone) is.

$$Skylark_{pop} = 1.73 - - 1.49{*}Area_p - 5.22{*}Area_{np} - 0.7{*}MPS_p + 2.14{*}MPS_{np} + 1.35{*}MFRACT_p - 0.32{*}MFRACT_{np}$$

where $Skylark_{pop}$ is the Eurasian skylark population; p represents patches of preferred land cover types, and np represents patches of nonpreferred land cover types; MPS is mean patch size; and MFRACT is mean fractal dimension index.

4. Discussion

Numerous studies showed the relationship between skylark abundances and habitat type in small study areas and at the regional level (e.g. Gevers et al., 2011; Guerrero et al., 2012; Mag et al., 2011; Nagy et al., 2009; Perkins et al., 2000; Wretenberg et al., 2007). Our MMM dataset, the large-scale (high-resolution) EMH LULC dataset and the regional-scale CLC dataset provided a unique chance to acquire regional (countrywide) information at different scales. We found significant statistical relation between the characteristics of different LULC types (total areas, shape, and size) and the abundance of this farmland bird, thus we demonstrated that the population density of farmland birds could be estimated from landscape structure at different grain sizes (by buffer zones). However, a precise estimation would require the incorporation of local habitat parameters, such as vegetation structural characteristics, land use intensity in the models.

4.1. Impact of landscape composition on skylark-abundance data

We analyzed the skylark's land cover habitat choices (preferred and nonpreferred) based on the EMH LULC local-scale dataset and the CLC regional-scale dataset. Although at different scales, the skylark's preferred and nonpreferred LULC classes derived from the two different LULC datasets were otherwise totally matched. These results suggest that the scale of the LULC datasets used does not have a significant influence on the identification of skylark habitat in terms of LULC classes. Our results indicate that the habitats of the skylark are arable lands, meadow, pasture, and grassland, which showed a significant positive relationship with skylark abundance. We considered these LULC categories as the preferred land cover types for the skylark. Arable land is a well-known habitat type for this farmland-bird species (Csikós and

Table 5
The level of statistical relations (estimated parameter values) between the skylark abundance values and the landscape composition and configuration (explanatory) variables of generalized linear models after multimodel averaging of best-candidate models; LULC land use land cover; N.S., not significant. Bold numbers are significant at 0.001 level, and nonbold at 0.01 level.

	300-m-radius buffer zone		600-m-radius buffer zone		1200-m-radius buffer zone	
	EMH	CLC	EMH	CLC	EMH	CLC
Total area of preferred LULC categories (ha)	**1.1022**	**−0.9154**	1.3686	**0.5691**	**0.5678**	**−1.488**
Total area of nonpreferred LULC categories (ha)	**−2.0588**	**−3.7049**	N.S.	**−2.9654**	**−4.6624**	**−5.2209**
AWMPS of preferred LULC categories	**0.7932**	**−0.6236**	**0.952**	**−0.7457**	N.S.	**−0.7024**
AWMPS of nonpreferred LULC categories.	N.S.	**0.8678**	N.S.	**1.5422**	**4.5249**	**2.1365**
AWMFRACT (preferred LULC categories).	**1.9509**	**0.8089**	**2.1966**	**1.7729**	**4.4742**	**1.3489**
AWMFRACT (nonpreferred LULC categories	**−0.3438**	**−0.5691**	**−2.3681**	**−0.7122**	−0.601	**−0.3166**

Negative relation								Positive relation

Table 6
Accuracy of estimated abundance values calculated as Spearman correlations between estimated abundances from training datasets and the testing data set, land cover. All correlations were significant at Level 0.01. [CLC: Corine Land Cover; EMH, Ecosystem Map of Hungary].

	300-m radius		600-m radius		1200-m radius		Number of of data pairs
	EMH	CLC	EMH	CLC	EMH	CLC	
Spearman's Rho	0.642	0.574	0.638	0.584	0.533	0.581	1678

Szilassi, 2020; Dietzen et al., 2014; Hoffmann et al., 2018, 2016; Praus and Weidinger, 2015). Unfortunately, accurate, detailed country-scale data on crop types cultivated within arable fields are not available for Hungary, therefore we could not analyse the effect of crop type on skylarks. Skylarks' preference for grasslands and pastures is well-known (Csikós, 2020; Csikós and Szilassi, 2020; Hamer et al., 2006; Koleček et al., 2015; Moreira et al., 2005; Piha et al., 2003; Reif and Hanzelka, 2016; Szilassi et al., 2019).

Artificial land, water land, forest, and swamp land cover types showed a significantly negative statistical relationship with skylark-abundance data. Several studies (Gottschalk et al., 2010, 2011; Guerrero et al., 2012; Szilassi et al., 2019) and recent national study (Szép et al. 2021) corroborate our findings. Forest and wetland LULC categories are well-known to be avoided by skylarks. The main reason for the significant negative relation of the forest is the lack of landscape openness, which apparently is a very important characteristic of skylark habitat (Berg et al., 2015; Csikós and Szilassi, 2020; Sauerbrei et al., 2014; Szilassi et al., 2019).

4.2. Impact of landscape configuration on skylark abundance

We found that skylark abundance increases if the preferred LULC patches possess a complex shape while nonpreferred patches are more compact in the landscape (Csikós and Szilassi, 2021; Donald et al., 2001; Gil-Tena et al., 2015; Hamer et al., 2006; Moreira et al., 2005; Perkins et al., 2000) (Table 5). However, in Hungary, this relationship is only shown for landscape metrics calculated from the local-scale EMH LULC database, which represents landscape structure at a very detailed scale. The skylark preferred land cover types of EMH-sourced AWMPS and AWMFRACT show a significant positive relation with skylark-occurrence data. This farmland bird prefers large patches of grassland with complex shapes, and the more grassland that can be found within the landscape, the larger the skylark population.

The statistical relations obtained from the CLC database, although significant, were not entirely clear because of the CLC scale limitations. Regional-scale patches cover large areas that include many agricultural parcels and other smaller LULC patches. Landscape structure cannot fully be explained by regional-scale CLC data-based landscape indices'. Clearly, regional-scale LULC maps-based calculations of the landscape indices AWMPS and AWMFRACT do not reliably represent the characteristics of the landscape structure. This is a limitation of the regional-scale (continental) LULC database, while the local-scale EMH database is a more useful tool for estimating skylark abundances.

4.3. Impact of grain size on estimation of skylark abundance

Our results showed that the scale of the land cover datasets and the size of the landscape windows (grain size) significantly affects the relationship between the skylark abundance and landscape structure (Fig. 2; Table 6). Each of the investigated buffers (i.e. 300-m, 600-m, and 1200-m radii) shows a significant statistical relation between skylark-abundance data and the spatial configuration of skylark preferred and nonpreferred patches. Rahman et al. (2012) showed that not onlythe local grain size defined in a 100-m buffer zone is an important landscape variable, but the surrounding landscape characteristics are also important factors in skylark population density. We found a significant relation between the density of skylarks and the landscape composition. Using EMH data, we found that only the AWMPS of the skylark nonpreferred LULC patches showed no significant relation with skylark-abundance data within the 300-m- and 600-m-radii buffer zones. This phenomenon can be explained by the small area of skylark nonpreferred patches inside the relatively small buffers (28.27 ha within the 300-m-radii buffer zone and 113.09 ha within the 600-m-radii buffer zone). The AWMPS of the skylark preferred LULC patches (EMH data) does not show significant statistical relation with the skylark abundance data only within the 1200-m-radius zone. Presumably, this buffer is too large to have detectable effect of landscape structure (MPS of the skylark-preferred land cover patches).

We found a negative relation between preferred LULC (CLC) classes and skylark abundance in the 300-m- and 1200-m-radii buffers due to the small resolution (25-ha minimum mapping unit) of this LULC dataset. In the 300 m-radius buffer zone, only one or two LULC types were included on average, whereas the 1200 m-radius buffer zone is too large an area for the skylark as it goes beyond the observation zone of this bird.

Šímová and Gdulová (2012) found that an increase in grain size indicates an increase in AWMPS values. The AWMFRACT values of preferred LULC categories based on EMH had a strong effect on skylark population density at large grain size. This landscape index had the strongest effect on skylark abundance in the 1200-m-radius buffer zone. Still, the skylark nonpreferred LULC categories in both datasets have the strongest negative effect on skylark occurrences within the 600-m-radius buffer zone. Several authors claim that AWMFRACT contrasting effects and the scale dependance of the AWMFRACT landscape index is unclear (Šímová and Gdulová, 2012; Uuemaa et al., 2005; Wu, 2004). Our study also does not show any relationships between the values of the AWMFRACT of the skylark nonpreferred LULC categories and grain size, whereas other studies have discovered negative or positive relations (Baldwin et al., 2004; Hargis et al., 1998; Šímová and Gdulová, 2012).

The importance of scale depends on the type of investigated farmland-bird species and the landscape-pattern characteristics of the study area. It is essential to find the optimal grain size and for input from LULC datasets, if we aim to improve the accuracy of our results. The approporiate scale is also important for the implementation of landscape ecological studies, such as landscape planning and management, forest management, biodiversity protection, and urban planning, because results based on an inappropriate scale may be misleading (Šímová and Gdulová, 2012).

4.3.1. *Scale sensitivity of skylark-abundance modeling*

We have proven the importance of scale sensitivity in habitat modelling and when using the LULC datasets, and grain size also is emphasized by other authors (Buyantuyev and Wu, 2007; Šímová and Gdulová, 2012; Uuemaa et al., 2005; Wu, 2004). Our results show that both the local-scale EMH and the regional-scale CLC databases are suitable for estimating bird densities (in our case, the Eurasian skylark), although the accuracy of the estimation is presumably related to other factors (crop type, use of chemicals, etc.), not considered in our model because of the lack of data. Our results could improve recent modelling of distribution and population size of the skylark in regional and national levels (e.g. Szép et al. 2021) using local/regional scale habitat data.

Using local-scale EMH data, the configuration of the land cover within the 300-m-radius landscape window is best for estimating the number of skylarks. Still, even the landscape structure within the 600-m-radius buffer zone is a relatively good estimator of the number of skylarks. Landscape metrics calculated on the basis of the continental-scale CLC dataset may also help estimate numbers of skylark individuals within a 600-m-radius buffer. Other authors have confirmed the importance of this zone for farmland birds (Engel et al., 2012; Miguet et al., 2013; Szilassi et al., 2019).

5. Conclusions

In our study, we investigated the feasibility of estimating the number of skylark individuals at different scales of land cover maps. Our results indicate that the best approximation (41.2% and 40.7% accuracy) of skylark abundances can be estimated based on the 20 × 20-m resolution (Hungarian) land cover map in the 300-m- and 600-m-radii buffer zones. The regional-scale low-resolution Corine European land cover database is also suitable for estimating the number of skylark fauna, although the best estimate was obtained in the 1200-m-radius buffer zone (34.11% accuracy). Our results are important for modeling the number and density of farmland-bird species in areas where detailed bird-monitoring survey data and information on crop structure are not available. The outcomes of this research also help landscape-scale conservation management decisions.

CRediT authorship contribution statement

Péter Szilassi: Conceptualization, Methodology, Writing – original draft. **Róbert Gallé:** Writing – review & editing, Supervision. **Tibor Szép:** Data curation, Supervision, Validation. **Nándor Csikós:** Visualization, Writing – review & editing, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Appendix 1 Descriptive statistics of Eurasian skylark-abundance data.

	Mean	Maximum	Minimum	Standard deviation
Eurasian skylark- abundance data.	1.75	22	0	2.74
Distance between observation points.	507 *m*	1000 *m*	500 *m*	42.3 *m*

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