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DOCTORAL SCHOOL OF GEOSCIENCES

Analysis of the relationship between land cover change and abundance data of Eurasian skylark *(Alauda arvensis)*

A felszínborítás változás és a mezei pacsirta *(Alauda arvensis)* egyedszáma közötti kapcsolat vizsgálata

PhD Thesis

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1. Introduction

Arable land is the most common anthropogenic land cover type of the world (38%) as well as of Europe (45%) (Fao 2016, EBCC 2015). In Europe, the diversity and quantity of farm-land bird populations linked with agricultural environments has drastically decreased. Almost every European country is affected by this trend (Chamberlain et al., 1999; EBCC, 2020; Herzon et al., 2014; Nagy et al., 2009; PECBMS, 2019; Wuczyński, 2016). Many authors argue that the abundance of farmland birds in Europe is strongly linked to agricultural cultivation intensity, landscape structure, and crop heterogeneity. (Gil-Tena et al., 2015, 2008; Moreira et al., 2005; Piha et al., 2007; Suárez et al., 2003).

Different drivers of landscape (land use/land cover) change exist in Western- and Central-Eastern Europe, all of which have an impact on the abundance of farmland birds (Tryjanowski et al., 2011). Because the members of the European Union have set their own climate protection objectives, the main driver in Western Europe (in this case Germany) was the support of renewable energies (EU, 2009; European Commission, 2017). Many countries (including the United States, China and many European states) rely on various renewable energy sources (Gao et al., 2019; Sahoo et al., 2018; Van der Horst et al., 2018). In the EU, 7.6% of renewable energy production comes from biogas, which is mostly electricity (EEA, 2017). 69% of biogas production comes from anaerobic co-digestion of waste and agricultural products like energy crops and manure (European Commission, 2021).

Alternative energy systems are reshaping the landscape, resulting in the coining of the term "energy landscape." Wind turbines near the coast, biogas power plants in agricultural areas, and solar panels near roads are all examples of how these energy systems are changing the landscape. Calvert et al. (2019) define an energy landscape as an area whose geographical characteristics is suitable for a specific type of energy production system, which is nowadays mostly renewable energy. The changes of these energy landscapes are spatially and temporally more dramatic than the changes of other European landscapes (Brandt and Glemnitz, 2014; Lüker-Jans et al., 2017; Lupp et al., 2014).

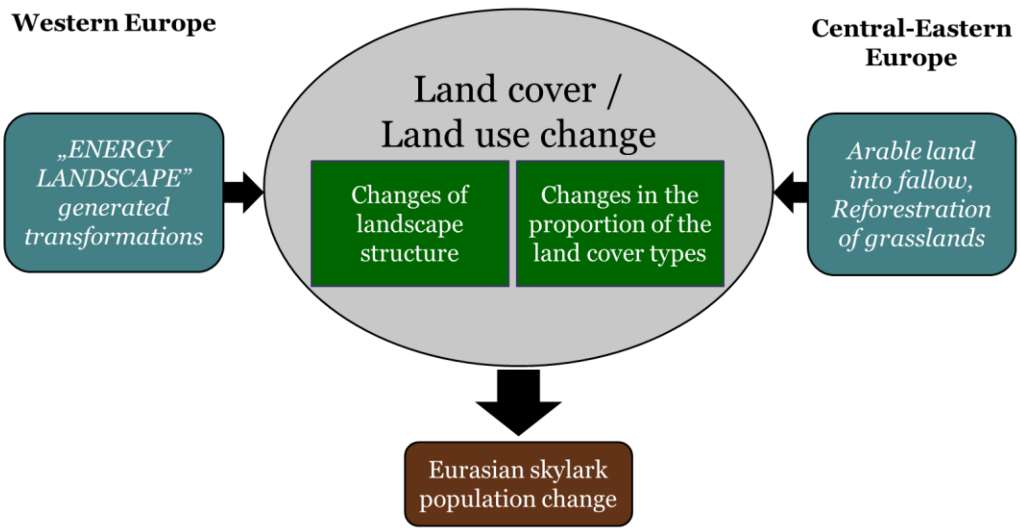

Figure 1.1. Drivers of land cover and landscape structure change in West- and Central-Eastern Europe

Germany accounts for half of the EU's total biogas energy production (European Commission, 2017). Because of the adoption of a renewable energy law in 2000, which was revised in 2004 and 2009 to encourage a surge in biogas production, the majority of the biogas is needed to produce electricity (Scheftelowitz et al., 2018). For new biogas power plants, the law ensures a high and stable feed-in tariff and it established a bonus for using renewable substrate materials like energy crops and manure (Scheftelowitz et al., 2018). More than 10,000 biogas power plants, with a total installed capacity of 4500 MW, are mostly operated by local farmers (Scheftelowitz et al., 2018). The conversion from an agrarian to an energy landscape has numerous consequences, mostly caused by the energy crop production. Changes in ecosystem services (Lupp et al., 2014), biodiversity (fauna and flora) (Brandt and Glemnitz, 2014; Schleupner and Link, 2008), land use (Csikos et al., 2019; Laggner et al., 2014; Lüker-Jans et al., 2017), and landscape structure (Csikos et al., 2019; Link and Schleupner, 2007) have been observed as a result of the adoption of biomass energy. Increased soil erosion (Duttmann et al., 2011), nitrogen mineralization (Klu, 2013; Svoboda et al., 2013), and greenhouse gas emission (Klu, 2013) are linked to the conversion of pastures and cereals to silage maize and changes in the biodiversity (Brandt and Glemnitz, 2014; Link and Schleupner, 2007). Changing from an agrarian to an energy landscape usually results in changes in landscape heterogeneity (LULC).

Another driving force of LULC changes is the agricultural policy of the European Union. In the 1990s, the European Union's common agricultural policy (CAP) and land privatization modified dramatically the landscapes of Central and Eastern European (CEE) countries. Land abandonment and reforestation were the main drivers of landscape change. (Báldi and Faragó, 2007; Szép et al., 2012; Tryjanowski et al., 2011). Lands with poor soil quality and agro-ecological conditions have been abandoned in Hungary and other CEE (post-socialist) countries (Szilassi, 2015; Szilassi et al., 2017; Szilassi et al., 2019). Land abandonment results in the transformation of arable lands into non-cultivated lands, as well as the rapid and spontaneous reforestation of grasslands (Figure 1.2.) (Gil-Tena et al., 2015; Tryjanowski et al., 2011).

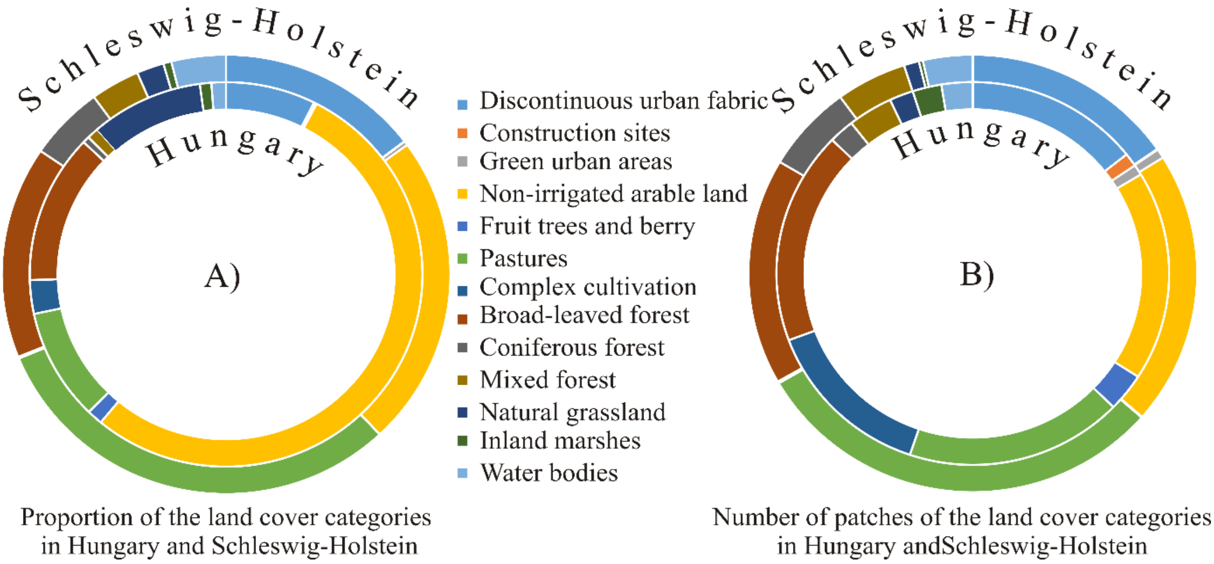

Figure 1.2. Proportion of land cover categories (A) and number of patches by land cover categories (B) in Hungary and Schleswig-Holstein Federal State

Both of the above described LULC change processes have important impact on the avifauna of the agrarian landscapes. Most of studies are focusing on the connection between the land use/crop structure and agricultural fauna population in parcel scale (Hamer et al., 2006; Jerrentrup et al., 2017; Koleček et al., 2015; Rahman et al., 2012; Reif and Hanzelka, 2016). Because this species is one of the most characteristic farmland birds of European agricultural landscapes, the abundance data of the Eurasian skylark was used to analyse the impact of LULC change on the agrarian fauna as an indicator bird species (Achtziger et al., 2004; Butler et al., 2012; Hoffmann et al., 2016; Wakeham-Dawson, 1995). It is necessary to identify the skylark preferred and non-preferred land cover types in order to establish a link between the species' decline in population and regional land cover change. Between 2000 and 2018, the population of the Eurasian skylark in the European Union decreased dramatically: Norway -47%, Lithuania -41%, France -38%, Czech Republic -29%, Hungary -24% and Germany -17%.

For the winter season, most skylarks migrate to the Mediterranean region from Hungary and Germany (Csörgő et al., 2009). Except for the Nearctic and high mountains, the skylark was introduced to the Americas, Asia, Australia, and New Zealand (Cramp, 1988). Most of Central European breeders migrate to the Mediterranean areas for the winter. (Csörgő et al., 2009). The Eurasian Skylark is the most characteristic bird of Hungary's agrarian landscapes, and a small number of them are residents (Csörgő et al. 2009). In the agricultural districts of Schleswig-Holstein Federal State, the skylark is one of the most characteristic bird species.

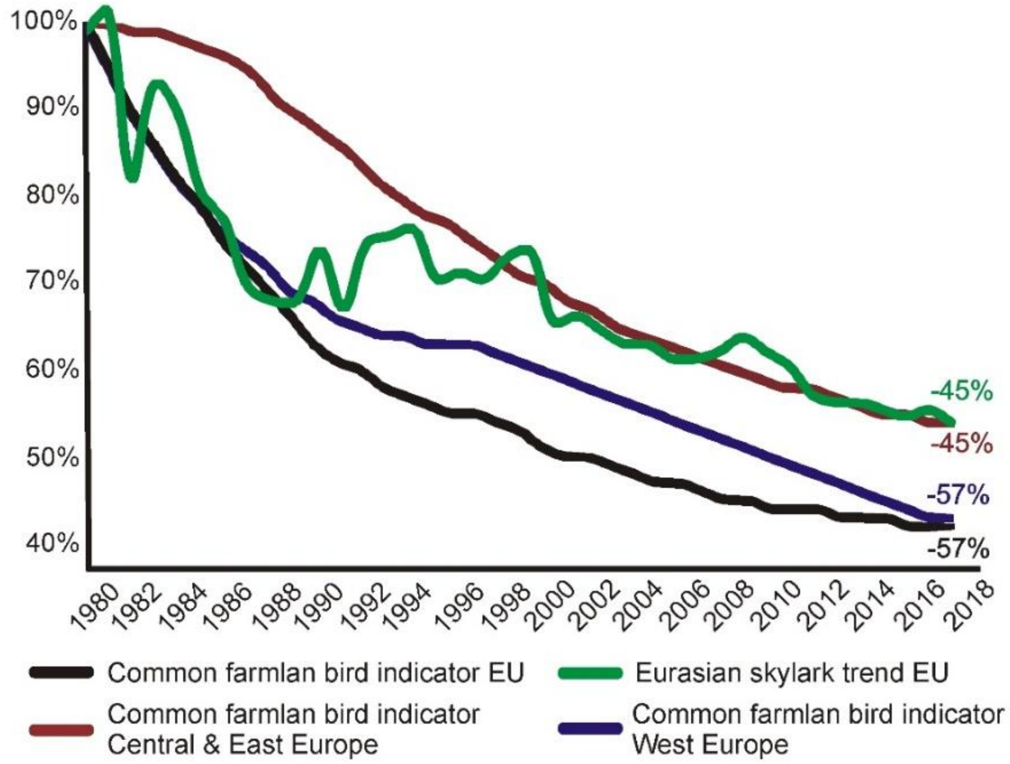

Figure 1.3. Trend lines of common farmland birds and Eurasian skylark (Alauda arvensis) in Europe

In my thesis, I will identify those areas, where the traditional agricultural landscape changed into an energy landscape in Schleswig-Holstein, where the driver of the landscape change was the spread of renewable energy technology (especially the plantation of biogas energy plants). One part of the thesis focuses on quantifying land use and landscape change processes induced by the intensification of silage maize cultivation for biogas production in Schleswig-Holstein case study area. Landscape metrics and LULC diversity indicators, I suspect, are appropriate for monitoring the effects of energy policies on the structure and diversity of agricultural landscapes, which are increasingly used for energy production. Based on the installed electrical capacity density of biogas power plants in Schleswig-Holstein, I would like to delineate different landscape change impact zones. According to my hypothesis, the biogas production has a significant impact on the agrarian bird population of these areas. To demonstrate the utility of this method, I would like to look at the distribution and changes of land use categories and landscape indices within the "energy landscape impact zones".

To investigate the links between the Eurasian skylark and changes in land cover and land use (crop) heterogeneity, first, I would like to investigate the cause of the changes, which is the establishment of biogas power plants and the production of energy crops such as silage maize and rape. This relatively fast and significant change in the landscape, as well as its impacts on biodiversity, crop heterogeneity, and the abundance of farmland birds, has not been clarified yet (Csikos et al., 2019). In case of the Federal State of Schleswig-Holstein (Germany) study area, only a few references have studied this topic (Leuschner et al., 2014; Riedel, 2013; Schleupner and Link, 2008). There have been no studies that have previously analysed the relationship between the abundance of Eurasian skylarks and the energy landscape created by landscape transformation. Because many studies have shown that the population of farmland birds in Europe is significantly linked to the intensity of agricultural cultivation, crop heterogeneity, and land use change, it is essential to investigate the effects of land use, land cover, crop heterogeneity, and crop structure change (due to the introduction of energy plants) on the population of skylark. (Gil-Tena et al., 2008; Gottschalk et al., 2010; Guerrero et al., 2012; Moreira et al., 2005; Verhulst et al., 2004).

In Hungary, a detailed land cover dataset will be used to investigate the relationship between the skylark population and the CAP related land cover change of this study area. The Hungarian Ecosystem Basemap (HEB), a very detailed (20 X 20m minimal mapping unit) LULC map, is used to describe the landscape structure of rural landscapes. Landscape indices are widely used as indicators of biodiversity and habitat changes, according to the pattern and process paradigm, which examines the relationship between landscape patterns, spatial distribution, and landscape processes (Borges et al., 2017; Szilassi et al., 2017; Uuemaa et al., 2013, 2009; Walz, 2011). I would like to estimate the combined impact of these variables on skylark population by calculating shape- and size-related class-level (for skylark preferred and non-preferred groups of LULC categories) landscape metrics as well as land cover heterogeneity (Borges et al., 2017; Csikós and Szilassi, 2020; Gil-Tena et al., 2015; Schlager et al., 2020; Peter Szilassi et al., 2019; Vögeli et al., 2010). By my hypothesis, the population density of skylarks is determined based on the skylark preferred LULC categories and landscape indices (proportion of LULC categories, shape and size related landscape metrics).

I managed to obtain population datasets for Eurasian skylarks from both study areas, Hungary and Schleswig-Holstein. In Hungary, between 2000 and 2019 every year, approximately 800 field surveyors across Hungary conduct a nationwide bird-monitoring survey, which they then join into the Hungarian Common Bird Monitoring Database (MMM) (Szép et al., 2012; Szép and Gibbson, 2000; Szép and Nagy, 2001). The volunteers were not dispersed throughout Hungary at random. The observers were given the option of choosing their observation area in the survey. Each observation point received two spring visits, and the number of birds within a 100-meter radius of each point was observed (by hearing and visually).

The ornithological working group of Schleswig-Holstein and Hamburg (Ornithologische Arbeitsgemeinschaft für Schleswig-Holstein und Hamburg) also collected Eurasian skylark population data in Schleswig-Holstein, Germany. Between 2005 and 2009, the ADEBAR (Der Atlas Deutscher Brutvogelarten) project supported the survey. A total of 150 surveyors mapped all of Schleswig-breeding Holstein's bird species. I used the most recent abundance data from 2009 in 281 quadrants. I only used data from 2009 because it corresponds best to the CLC land cover (2006) and the 2010 agrarian census database.

For my European scale investigation, I will usethe grids of the bird surveys from the two study areas in the same grid size (5 × 5 km). Within the grids, the proportion of land cover types (all CLC categories) and the population of skylarks were determined. There were no homogeneous landscapes inside the grid. In both study areas, I will estimate the population density (individuals/hectare) and habitat change of skylarks at the local (NATURA 2000 areas of Hungary) and continental scales (Europe). Based on these results, the scale sensitivity of the data and the landscape window (grain size of the skylark's habitat) can be analysed.

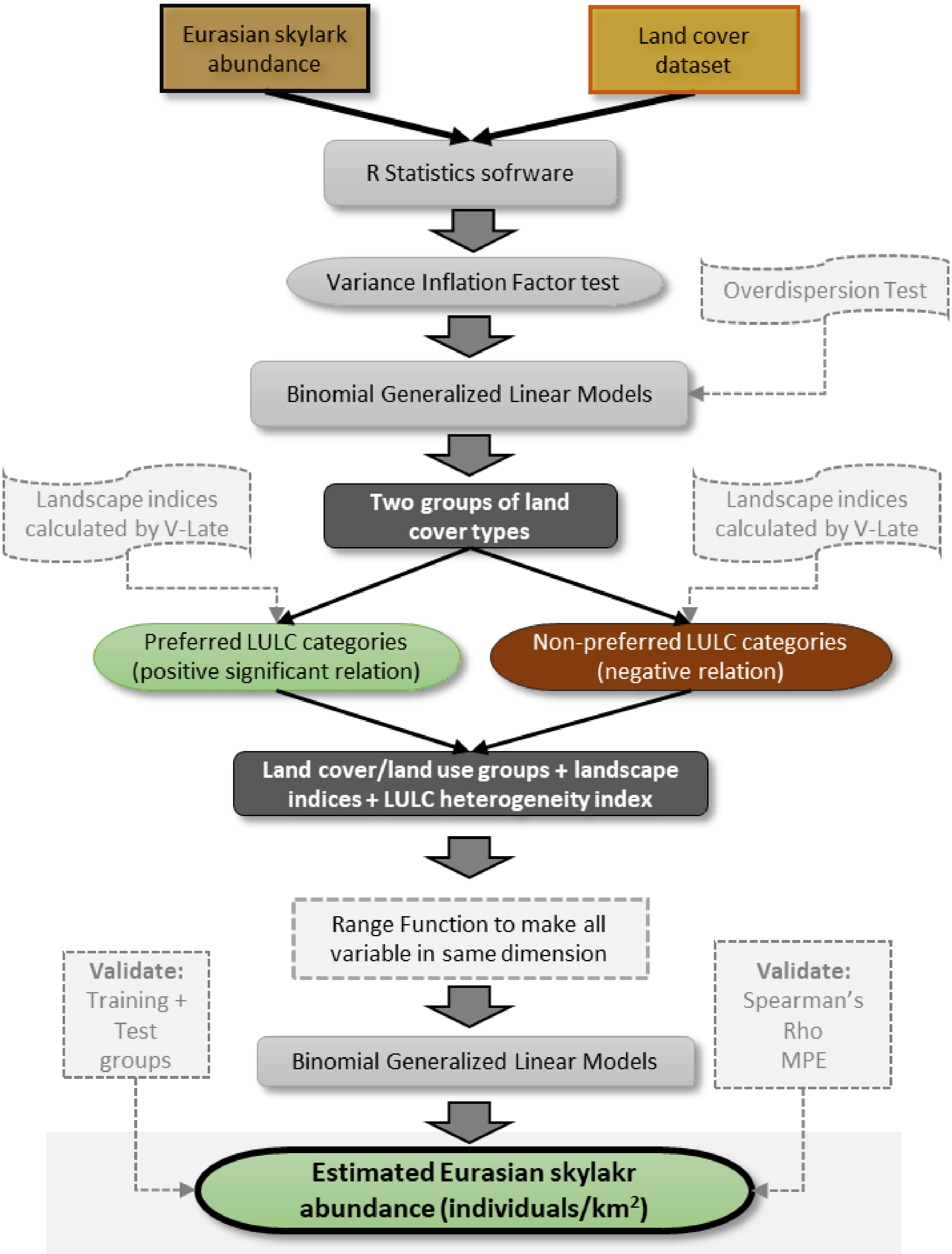

Figure 1.4. Flowchart for the logical structure of the data analysis of the research process

Throughout my thesis, I will use the R Statistics software for statistical analyses. I will use variance inflation factors (VIFs) to identify a group of correlated land cover and landscape index variables, and the explanatory variables were not linearly related. The impact of land cover and landscape structure (composition) on skylark population will be investigated using generalized linear models (GLM). I will apply negative binomial models (link=log) to account the overdispersion of skylark abundance data (tested by overdispersiontest function of *AER* package in R). I will create models with all possible combinations of explanatory variables and used the "dredge" function from the *MuMin* package in R to rank them using Akaike's information criterion (Barton, 2015). To account for uncertainty arising from the large number of candidate models, I will use model averaging for competitive models (delta AICc 2) (Burnham and Anderson, 2002). The significance of the variables will be estimated by the *LmerTest* package (Kuznetsova et al., 2020). Since the variables were in different dimensions, I will use R to create a *range function* that converted the values into a number between 0 and 1. The predicted marginal effects of the preferred land cover types and their landscape metrics on the skylark population will be calculated using the *ggeffects* package in R (Lüdecke, 2018). On the basis of my dataset in R statistics software, I will set up a training and a testing group (2/3 and 1/3, respectively) with random sampling (*sample.split* function from *caTools 1.17* package). The estimated skylark population data will be calculated using the predict function from the *car* package.

In my doctoral thesis, I will be able to describe the optimal landscape configurations of the skylark in European scale using European land cover databases after identifying the skylark's preferred and not preferred land cover types. As a result, my findings could be useful for further research of the relationship between recent changes in landscape composition (proportions) and configuration (spatial structure) of different LULC categories, and skylark abundance data in other EU countries. Through the thesis I will analyse the land cover, land use and landscape structure changes (mostly agricultural landscapes) during the last decades in Hungary, Schleswig-Holstein Federal State and Europe. The Eurasian skylark will be used as an indicator species to present the impact of the changes in the landscape (land cover and land use). Therefore, I would like to answer the following questions in my thesis:

- Based on the regional land cover dataset, what changes have occurred in the land cover categories in Hungary over the last 30 years?
- Which LULC categories are preferred or non-preferred by the Eurasian skylark in Hungary; and how they changed during the last decades and what are the possible future directions of landscape change?
- What are the hot spots of the transformation of traditional agricultural landscapes into energy landscapes in Schleswig-Holstein study area? How can we delineate the most transformed landscape units?
- What are the impacts of this transformation to energy landscape, analysed via size- and shape related landscape metrics as well as LULC diversity indices in the Schleswig-Holstein study area?
- What are the effects of the energy landscapes on the population of Eurasian skylark, based on the land cover categories, land use (crop types) and LULC heterogeneity in the Schleswig-Holstein study area?
- How does the landscape structure (shape and size related metrics, proportion of land cover categories) influence the population of Eurasian skylark based on a local scale land cover dataset in the two study areas (Schleswig-Holstein and Hungary)?
- What precision can be achieved in the estimation of the Eurasian skylark density based on a local scale land cover dataset?
- What changes have occurred in the European landscape over the last few decades, and how have these changes affected the Eurasian skylark population?

2. Recent and predicted changes in habitat of the Eurasian Skylark Alauda arvensis based on the link between the land cover and the field survey-based abundance data

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Abstract

The European avifauna on agricultural land has been permanently diminished over the past few decades. This phenomenon is clearly connected with agricultural intensification and the recent land cover changes. The main aims of this study were to identify the land cover preferences of a farmland bird species, the Eurasian Skylark Alauda arvensis in Hungary and investigate the link between the recent trend of the abundance of this species and the land- cover change. We employed GIS and statistical methods to assess the link between the abundance of this species based on the Hungarian common bird monitoring database (MMM) and the spatial proportion of the Corine Land Cover (CLC) categories in different buffer zones with 300, 600 and 1200 m from the observation points. Based on the significant statistical connections, we could identify and select land cover categories that serve as habitats and land cover categories that this bird species does not inhabit. The land cover preference of the Eurasian Skylark, in case of some land cover category, is depending on the grain scale (circle radius distance from the observation points). In analyses arable lands has been omitted because this land cover type is the well-known habitat of the species. According to our results, the Eurasian Skylark prefers permanent crops (vineyards, fruit trees and berry plantations) inside 600m and 1200m buffer zones, and pastures inside 1200m buffer zones, while it does not prefer urban fabric areas and heterogeneous agricultural, forests, and wetlands or water bodies inside 300m and 600m, scrub and/or herbaceous vegetation associations (transitional woodland-shrub and natural grassland areas) inside the 600m and 1200m radius buffer areas. The identification of these regional (European level) land-cover categories allowed us to analyse the recent (1990–2012) and the predicted (2006–2050) characteristics of habitat changes of this bird species, associated with land cover change. Based on our results, we could estimate that the Skylark habitat will decrease by 188 560 ha between 2006–2050 in Hungary.

Key words: Eurasian Skylark, agrarian landscapes, CORINE, land-cover, habitat change, farmland bird

2.1. Introduction

Arable land is the most widespread anthropogenic-based land-cover category in the world (38%) as well as in Europe (45%) (Fao 2016, EBCC 2015). Species richness and abundance of farm- land birds associated with agricultural landscapes has declined dramatically in Europe. This process is significant in almost every European country (Chamberlain et al., 1999; EBCC, 2020; Herzon et al., 2014; Nagy et al., 2009; PECBMS, 2019; Wuczyński, 2016) including in Hungary, which is part of the Pannonian biogeographical region (Báldi et al., 2005; Báldi and Batáry, 2011a, 2011b; Szép et al., 2012). Many authors underlays that the abundance of farmland birds in Europe is strongly connected with the intensity of agricultural cultivation, the landscape structure and the crop het- erogeneity (Gil-Tena et al., 2015, 2008; Moreira et al., 2005; Piha et al., 2007; Suárez et al., 2003).

Land privatisation in the 1990s and the common agricultural policy of the EU has caused dramatic landscape changes in Central and Eastern European (CEE) countries (Tryjanowski et al., 2011). There are two contradictory processes occurring simultaneously in the agricultural land of EU member countries. On the one hand, more intensive forms of agriculture have become dominant on land with good production potential, and the proportion of grasslands and pastures has decreased. On the other hand, especially in Hungary and other post-socialist CEE countries, lands with poor agroecological conditions have been abandoned. Land abandonment allows spontaneous and rapid reforestation (Butler et al., 2007; Gil-Tena et al., 2008; Krebs et al., 1999; Stoate et al., 2001; Tryjanowski et al., 2011). Most of the studies are focusing on parcel scale studies, analysing the relationship between the crop structure and Eurasian Skylark's abundance (Hamer et al., 2006; Jerrentrup et al., 2017; Koleček et al., 2015; Rahman et al., 2012; Reif and Hanzelka, 2016), however there are less studies which analyse the link between the Eurasian Skylark and recent land-cover changes (Moreira et al., 2012; Reif and Hanzelka, 2016). Although large-scale studies describe the land- scape ecological significance of micro-habitats (e.g., grassland edges and hedgerows) or crop diversity (Josefsson et al., 2013; Kuiper et al., 2013; Odderskær et al., 1997; Schön, 2011; Wakeham-Dawson and Aebischer, 1998), for country and European level analyses of the recent habitat changes, we need to identify land-cover types on a regional (European) scale that are the habitats of a given species.

The Eurasian Skylark is the most characteristic bird of Hungary's agrarian areas, and a small number of them are residents, however, most of them leave the country and spend the winter in Mediterranean countries (Csörgo et al., 2009). The species can be found all over the rural agrarian landscapes of Europe, it is widespread in the Americas, and it has also been introduced into Australia and New Zealand (Cramp, 1988). Although the Eurasian Skylark preference for arable lands in small scale (crop structure, types of crops, optimal heights of crops etc.) is well known, but in the landscape scale, the optimal landscape composition characteristics of the Skylark are not clear yet. To reveal the connection between recent Skylark abundance decline, and regional land cover change, it is important to identify the Skylark preferred, and non-preferred land cover types. Similarly, to other skylarks, Eurasian Skylark nests on the ground and always stays close to the ground (Donald et al., 2006). We studied the landscape level (regional scale) ecological background of the abundance data of the Eurasian Skylark. We used a decade of country level, spatially very diverse field monitoring data on the abundance of Skylark in Hungary (Szép et al., 2012). This dataset gives us a unique opportunity for regional scale analyses of the optimal landscape composition of this species. Identification of Skylark-preferred and not preferred land cover categories is important to estimate the recent and further change of potential habitat, and help to describe optimal landscape composition.
In the present study we analysed the relation- ship between the abundance of the Eurasian Skylark in Hungary and the proportion of CORINE Land Cover (CLC) categories. Based on the statistically significant connections between the land-cover types and Skylark abundance, we estimated the recent and further habitat change of Skylark on a regional level. After identifying the Skylark ‘preferred’ and ‘not preferred’ land cover types we will be able to describe the optimal land- scape configurations of the species in European scale using European land cover databases. Therefore, our results can be useful for further analyses of the connection of the recent landscape composition change and the Skylark abundance data in other EU countries.

Our data on the abundance of the Eurasian Skylark were obtained from the Hungarian common bird monitoring (MMM) database that was established in 1999 (Szép et al., 2012). More specifically our research questions were: (1) What kind of land-cover categories do and which categories do not Eurasian Skylarks prefer as habitats? (2) How did the most important land cover types change during the last decades and what are the possible future directions of landscape change?

Our study may contribute to the estimation of the effect of land cover change related trends on the Skylark abundance. We also investigated the grain scale sensitivity of our results analysing the statistical connections between the land cover characteristics and the Skylark abundance in different (300 m, 600 m and 1200 m radius) buffer zones from the Skylark observation points.

2.2. Materials and methods

2.2.1. Study area

Hungary is located in the Carpathian Basin (45°43’ to 48°35’N and 16°06’ to 22°53’E) in Central Europe. The total area is 93,033 km^2, and its elevation ranges from 77 m to 1014 m a.s.l. According to Farkas & Lennert (Farkas and Lennert, 2015) the most important land cover type is agricultural area. 61.0% of Hungary is covered by arable fields and managed grasslands, forests cover 20.7% of the country, and the proportion of built-up areas and other artificial surfaces is 5.5%. The greatest land cover diversity is on the hillslopes of the mountain ranges, in the hills and in the sandy areas. These are the most mosaic-like agrarian land. As a result of an agricultural policy change the extant of arable lands and pastures declined while the proportion of forests and abandoned lands increased during the last three decades (Biró et al., 2013; Loczy, 2015; Mezősi, 2011). This process was a general trend in post- socialist Central European countries following land privatisation in the 1990s (Reif and Hanzelka, 2016; Tryjanowski et al., 2011). Another important land cover change process with high ecological importance is the permanent increase of built-up areas especially in suburban zones of municipalities, due to the rapid urban sprawl (Szilassi, 2015).

2.2.2. Skylark abundance - Hungarian common bird monitoring database (MMM)

A detailed, country-wide bird monitoring survey covering the entire area of Hungary was per- formed by approximately 800 field surveyors from 1999 to 2012, and their work resulted in the establishment of the Hungarian common bird monitoring database (MMM) (Szép et al., 2012; Szép and Gibbson, 2000; Szép and Nagy, 2001). A total of 15442 observation points in UTM quadrants of 2.5 x 2.5 km serving as bird monitoring mapping units (BMMU) were delineated before the observations. In the present study we focused on observation points of arable fields, as the Skylark shows a strong preference for open field conditions, thus we analysed of data 3627 BMMU quadrants. Inside each BMMU quadrant, 5-minute-long point counts were carried out during two spring sessions, within a 100 m radius of 15 preliminary defined observation points (Latin square). Since 1999, the survey of the breeding populations was done twice each spring with a minimum of 2 weeks between the samplings, between mid-April and mid-June. The count was carried out between 5 and 10 am, when the wind speed was less than 5 m/s and there was no rain. The yearly maximum number of each observed bird species were calculated for each observation points. Between 1999 and 2012, 15199 observations were done by 762 observers during the breeding season. In the present study 7371 observation points data were used (Table 2.1.). We had three survey periods, fitting to the timescales of the CLC maps (2000, 2006, and 2012). The first ornithological survey period was conducted between 1999 and 2001, the second was between 2005 and 2007, and the third was conducted between 2011 and 2013 (Szép et al., 2012) (Figure 2.1.). Szép et al. (Szép et al., 2012) found an average 40% decrease in the abundance of the 17 typical farmland bird species in Hungary, among which 10 species (Perdix perdix, Coturnix coturnix, Merops apiaster, Galerida cristata, Alauda arvensis, Locustella naevia, Sylvia communis, Lanius collurio, Lanius minor, Miliaria calandra) had significant decline between 1999–2012.

Table 2.1. Description of the investigated observation points and the abundance data of the Skylark. Skylarks were counted in 100 m radius from the observation point.

	300 m radius buffer zone			600 m radius buffer zone			1200 m radius buffer zone		
	2000	2006	2012	2000	2006	2012	2000	2006	2012
Number of investigated buffer zones	835	565	807	1154	794	1081	1375	963	1286
Sum of skylarks	932	484	676	1396	793	1004	1717	1019	1860
Mean number of skylarks ± SD	1.12 ± 1.59	0.85 ± 1.45	0.83 ± 1.63	1.2 ± 1.63	0.98 ± 1.54	0.93 ± 1.64	1.25 ± 1.62	1.05 ± 1.54	1.44 ± 3.91

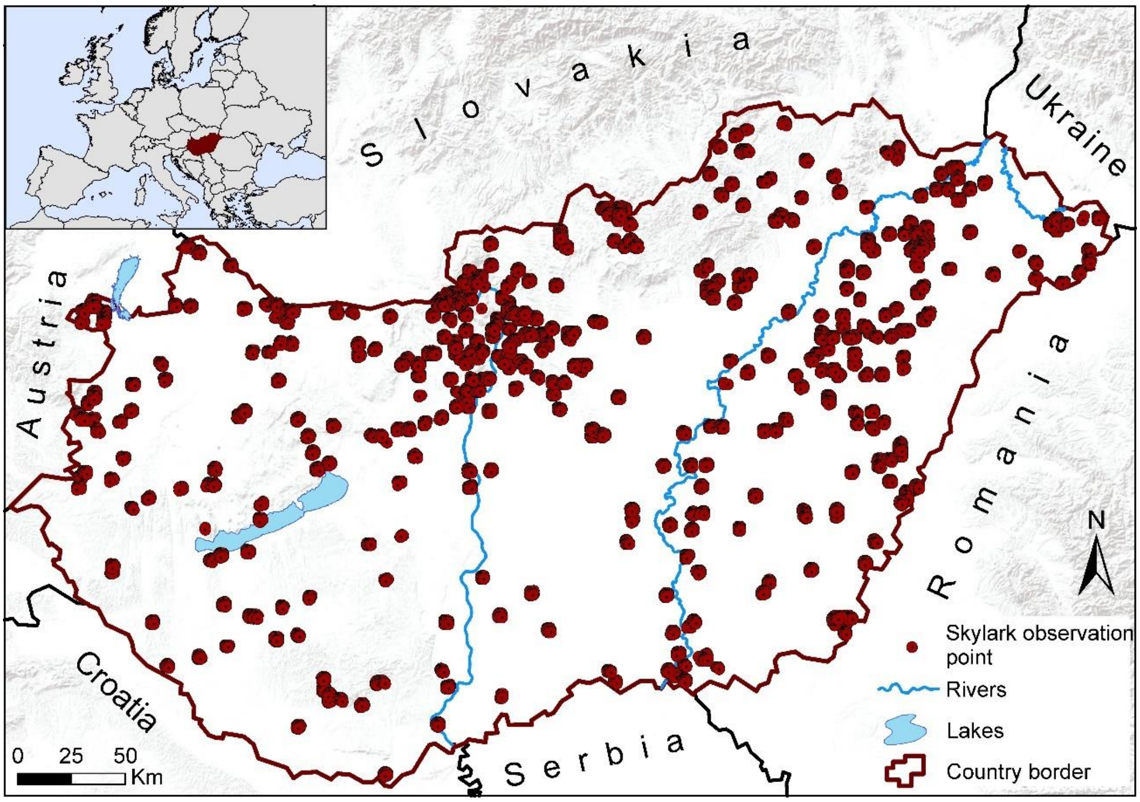

Figure 2.1. The spatial distribution of the MMM survey observation points of Hungary, where the Skylark occurred.

2.2.3. Habitat availability - The CORINE regional scale land-cover (CLC) database

The European CLC land cover maps were pre- pared by using a uniform methodology for the EU countries (EEA, 2006; EEA and ETC-TE, 2017). The scale of the maps is 1:100 000, the minimum map- ping unit was 25 ha for land cover patches with at least a 100 m width for linear landscape elements. Mapping was repeated every six years, thus three assessments of land cover have been available since 2000. In the case of Hungary, this digital database covers the total area of the country, and more than 40 000 land cover polygons were delineated and classified into 5 first level land cover classes, 13 second level, and 28 third level sub- classes (Appendix 2.1.), with at least an 85% thematic accuracy (EEA, 2006; Mari and Mattányi, 2002). The CLC database is widely used in regional scale ecological studies to identify and analyse bird habitats (Kiss et al., 2016; Martino and Fritz, 2008; Radović and Tepić, 2009). It also gives a unique opportunity to analyse the link between Skylark abundance and the proportion of the different land cover categories on a country level, and adaptation of our results in European scale (EEA, 2006). We are looking for the CLC 2000 database to the first MMM survey dataset (1999–2001), the CLC 2006 database to the second MMM survey dataset (2005–2007) and the CLC 2012 database to the third MMM survey dataset (2011–2013) using the MMM survey data. We revealed statistical connections between the percentage areas of the investigated CLC category and the yearly average abundance MMM data for the Eurasian Skylark.

2.3. Data analysis

We selected MMM survey points on agricultural areas and calculated the area of land cover categories (in hectares) for three different grain scales, 300 m, 600 m, and 1200 m (Engel et al., 2012), radius buffer from the CLC 1990, 2000, 2006, and 2012 databases. We excluded homogeneous landscapes, i.e. 100% agricultural fields, therefore the number of investigated buffer areas differ in case of each buffer radius (Table 2.1.). We performed preliminary tests to identify sets of correlated land- scape variables using variance inflation factors (VIFs), the explanatory variables were not linearly related as the VIF values were between 1.9 and 4.1. We used Generalized Linear Mixed Model (GLMMs) to determine the effect of landscape composition on the abundance (in the surrounding landscape of the observed individuals/agricultural observation points) of Skylark. Percentage value of urban fabric areas (CLC code:11), artificial, non-agricultural vegetated areas (CLC code:14), permanent crops (CLC code:22), pastures (CLC code:23), forest (CLC code:30), wet- lands or water bodies (CLC codes:41 and 51), scrub and/or herbaceous vegetation associations (CLC code:32) and heterogeneous agricultural areas (CLC code:24) we used as fixed terms (Appendix 1). The percentage areas of the arable lands (CLC code:21) has not been put into the model, because this land cover type is the well- known habitat of the Skylark. The year of observation was random effect in the models. We used negative binomial models to account over dispersion of the abundance data. We generated models with all possible combinations of explanatory variables. We used Akaike's information criterion to rank them with the 'dredge' function from the 'MuMIn' package in R (Barton, 2015). We per- formed model averaging for competitive models (delta AICc < 2) to include the uncertainty arising from the high number of candidate models (Burnham and Anderson, 2002). We estimated the significance of the variables with the 'LmerTest' package (Kuznetsova et al., 2018).

If there was a positive significant relationship (at $p < 0.05$) between the Skylark abundance and a given land cover category in case of at least one buffer zone, we classified that land cover category into the Skylark 'preferred' habitat. Negative significant connections between the Skylark abundance and a given land-cover category were classified as 'not preferred' habitats (Reif et al., 2018). Land cover categories that did not show significant statistical relationships with the Skylark abundance were defined as 'neutral' land cover categories.

2.3.1. Past and predicted changes of the Skylark 'preferred' and 'not preferred' habitats on a regional scale

Estimation of the past habitat area change of the Eurasian Skylark between 1990 and 2012. According to Engel et al. (Engel et al., 2012) the 600 m circle radius from the observation point is the most important habitat range for the Skylark, therefore we used these buffer zone areas for analyses of the past Skylark habitat change. Based on statistical analyses of the link between the land cover proportion (in 300 m, 600 m, and 1200 m buffer zones) and the Skylark abundance (in 100 m buffer zone) of each sampling point, we identified the Skylark 'preferred' and Skylark 'not preferred' land cover categories of the CLC 1990, 2000, 2006 and 2012 databases and estimate past habitat changes. For the analyses of habitat changes of the Skylark we used our results, and based on the literature data we added the 'arable lands' as preferred habitat, although this CLC type was take out from our model. We calculated the total estimated proportion of the habitat area (TEHC) with the following equation:

$$TEPH_{(y)} = \left(\frac{\sum TEPA_{(1-n)}}{TA}\right) \times 100$$

where *TEPA* is the total estimated proportion of the Skylark preferred area (%) in a given y year inside the 600 m buffer zones, where the MMM data was available, *n* is the total number of buffer zones, where the MMM data was available for a given *y* year, *TA* is the total area of the buffer zones, where the MMM data was available for a given *y* year.

$$TEPNH_{(y)} = \left(\frac{\sum TEPNA_{(1-n)}}{TA}\right) \times 100$$

where *TEPNA* is the total estimated proportion of the Skylark ‘not preferred habitats (%) in a given y year inside the buffer zones, where the MMM data was available. For the regional (country scale) mapping of the past habitat changes of the Skylark we calculated the total estimated proportions of the habitat (TEHC) and the ‘not preferred’ areas for the BMMMU quadrants too.

The predicted change of the Eurasian Skylark habitat areas between 2006 and 2050. Farkas & Lennert (Farkas and Lennert, 2015) modelled the future land cover map of Hungary for 2050. Based on neural Network analyses of the past CLC changes they modelled and calculated the total area of the main land cover categories of Hungary for 2050. They have also predicted the CLC changes between 2006 and 2050, and used the CLC 2012 data for validation of their results. We selected all ‘preferred’ and not ‘preferred’ CLC categories and modelled the further habitat changes of the Eurasian Skylark in Hungary until 2050.

2.3. Results

2.3.1. Identification of the Skylark habitats

The increase of the amount of pasture and permanent crops habitat types had a positive effect on Skylark abundance (Table 2.2.). According to our findings, the ‘pastures’ which are usually open grasslands, are optimal and very suitable habitats for the Skylark, but the proportion of this CLC category shows positive significant statistical connections with the Skylark abundance only in bigger grain scale (in case of the 1200 m radius buffer zone). Most of the ‘permanent crops’ CLC category involves orchard and vineyard areas in Hungary. It is surprising that these semi-open or closed land cover categories are showing positive significant statistical connections with the Skylark abundance data in case of the 600 m and the 1200 m radius circle buffer zones from the MMM observation points.

We classified those CLC categories which show negative significant statistical connections with the Skylark abundance data into the ‘Not preferred’ Skylark habitat category (Table 2.3.). The urban fabric areas and heterogeneous agricultural areas are ’not preferred’ areas for the Skylark inside all buffer zones. The forests and wetlands or water bodies are important ‘not preferred areas’ for the Skylarks only inside the closest zones (300 m and 600 m) from the observation points, while the scrub and/or herbaceous vegetation associations inside bigger grain scale (600 m and 1200 m) radius buffer areas can be defined as the ‘not preferred areas’.

*Table 2.2. Summary table for the 'Neutral' CLC category (which does not show any significant connections with the Skylark abundance data) and the 'Skylark preferred' CLC categories, which shows the GLMM results after multimodel averaging of best candidate models showing relative importance of each explanatory variable on Skylark abundance, estimated parameter values ± Standard deviation. (For detailed descriptions of the CLC categories see Appendix 2.2. and 2.3.). Significance levels: * — <0.05, ** — <0.01*

CLC code	Name of the CLC category	Variable	Relative importance. (Z values)	Multimodel estimate ± Standard deviation
14	Artificial, non-agricultural vegetated areas	area (%) in 300m radius buffer zone	14% (0.478)	0.003 ± 0.007
		area (%) in 600m radius buffer zone	30% (0.842)	-0.008 ± 0.009
		area (%) in 1200m radius buffer zone	72% (1.771)	-0.023 ± 0.013
23	Pastures	area (%) in 300m radius buffer zone	14% (0.362)	-0.000 ± 0.002
		area (%) in 600m radius buffer zone	59% (1.501)	0.003 ± 0.002
		area (%) in 1200m radius buffer zone	100% (4.511)	0.013 ± 0.004*
22	Permanent crops	area (%) in 300m radius buffer zone	78% (1.711)	0.007 ± 0.004
		area (%) in 600m radius buffer zone	100% (1.978)	0.007 ± 0.003*
		area (%) in 1200m radius buffer zone	100% (2.899)	0.013 ± 0.004**

*Table 2.3. Summary table for the 'Skylark not preferred' CLC categories, which shows the GLMM results after multimodel averaging of best candidate models showing relative importance of each explanatory variable on Skylark abundance, estimated parameter values ± Standard deviation. (For detailed descriptions of the CLC categories see Appendix 2.2. and 2.3.). Significance levels: * — <0.05, ** — <0.01, *** — <0.001.*

CLC code	Name of the CLC category	Variable	Relative importance. (Z values)	Multimodel estimate ± Standard deviation
11	Urban fabric area	area (%) in 300m radius buffer zone	100% (6.225)	-0.020 ± 0.003***
		area (%) in 600m radius buffer zone	100% (6.244)	-0.016 ± 0.002***
		area (%) in 1200m radius buffer zone	100% (6.300)	-0.018 ± 0.002***
24	Heterogeneous agricultural areas	area (%) in 300m radius buffer zone	100% (10.640)	-0.017 ± 0.001***
		area (%) in 600m radius buffer zone	100% (10.001)	-0.022 ± 0.002***
		area (%) in 1200m radius buffer zone	100% (9.533)	-0.034 ± 0.003***
31	Forests	area (%) in 300m radius buffer zone	100% (7.228)	-0.019 ± 0.002***
		area (%) in 600m radius buffer zone	100% (3.167)	-0.006 ± 0.002**
		area (%) in 1200m radius buffer zone	34% (1.237)	-0.002 ± 0.002
32	Scrub and/or herbaceous vegetation associations	area (%) in 300m radius buffer zone	15% (1.529)	-0.002 ± 0.004
		area (%) in 600m radius buffer zone	88% (1.968)	-0.006 ± 0.003*
		area (%) in 1200m radius buffer zone	89% (1.992)	-0.007 ± 0.003*
41 and 51	Inland wetlands and Inland water bodies	area (%) in 300m radius buffer zone	100% (3.216)	-0.020 ± 0.006**
		area (%) in 600m radius buffer zone	100% (3.798)	-0.021 ± 0.005***
		area (%) in 1200m radius buffer zone	12% (0.515)	-0.002 ± 0.005

2.3.2. The past and predicted changes of the Skylark habitats

Pastures, permanent crops, and arable lands ('preferred' habitats) of Skylark decreased permanently in Hungary over the past few decades. There was more than 3% loss of these habitats in the quadrants with Skylark data. The Skylark 'not preferred' areas experienced a moderate (more than 2%) increase (Figure 2.2.).

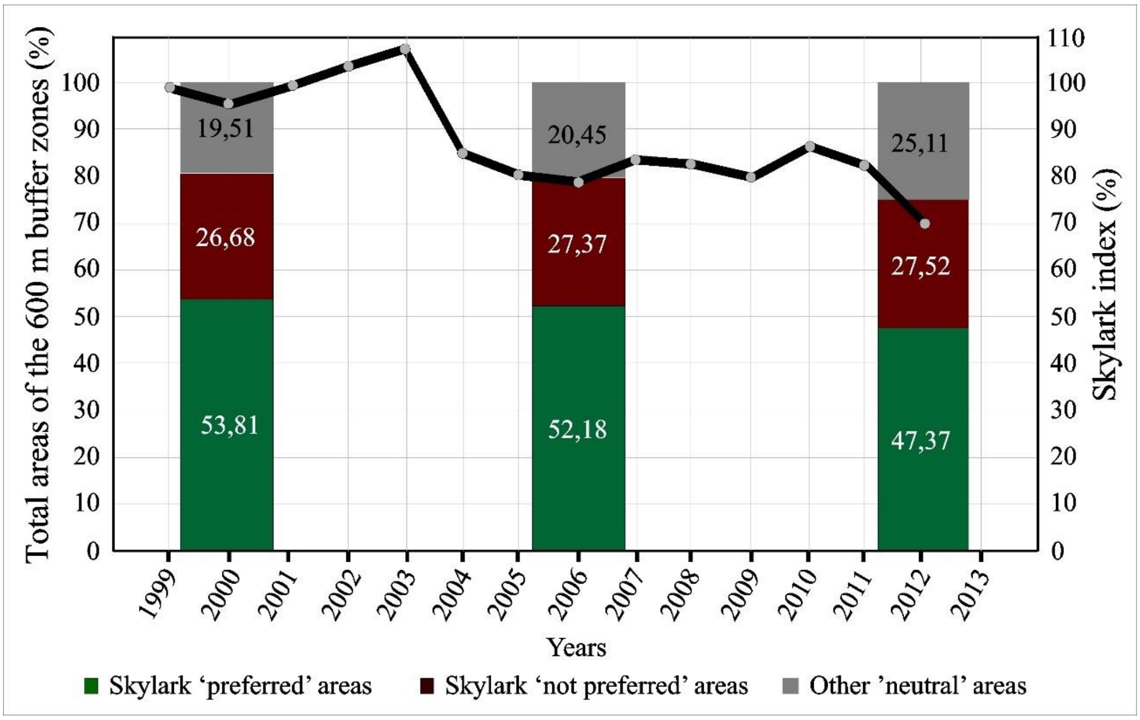

Figure 2.2. Proportions of Eurasian Skylark 'preferred' and 'not preferred' habitats in the 600 m circle radius buffer zones of the MMM observation points of Hungary where the MMM Skylark data were available in 2000, 2006 and 2012, and the change of the 'Skylark index' where 100% is the estimated Skylark population of Hungary in 1999 (data source MMM database). The arable land CLC category is included in the preferred areas.

Based on our results we can mapping the habitat changes of the Eurasian Skylark in Hungary (Figure 2.3.). The Skylark preferred areas increased by 9681 km^2 and the Skylark not preferred areas increased by 29162 km^2 between 2000 and 2012.

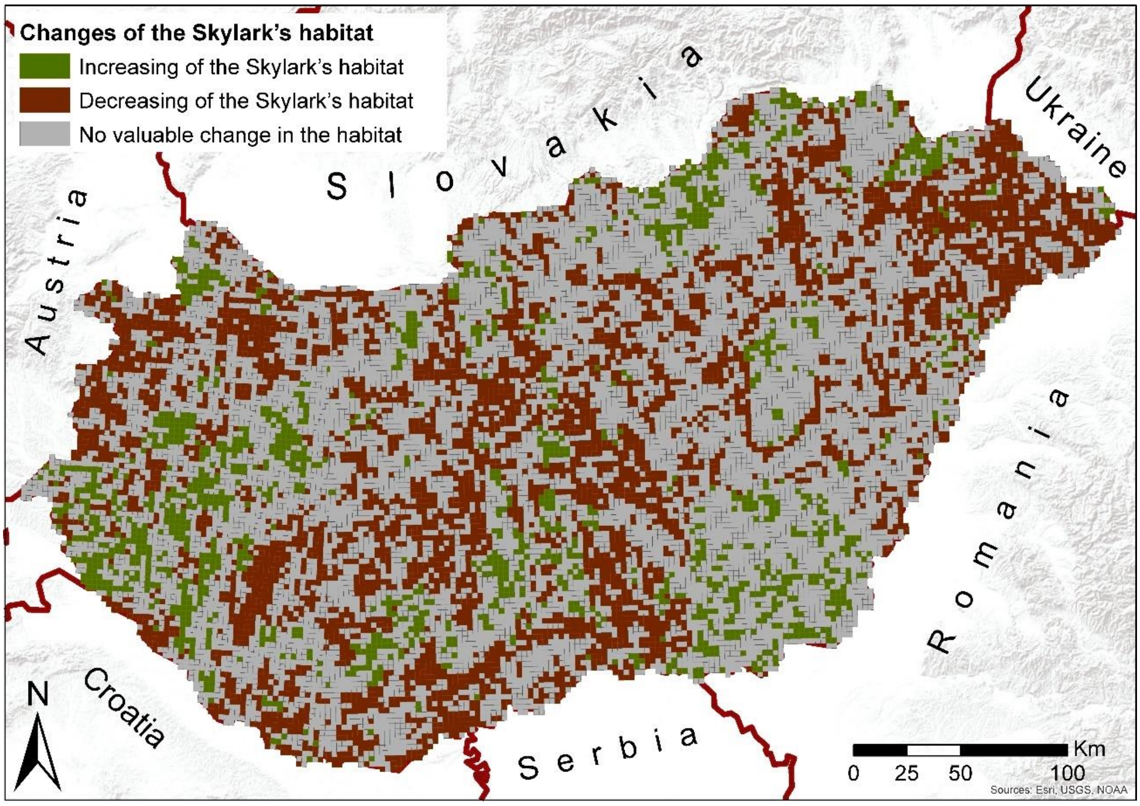

Figure 2.3. The habitat change map of the Eurasian Skylark between 2000 and 2012 in Hungary (based on CLC 2000–2012 land cover changes of each BMMU quadrants).

To put our results into the further land cover change models, we can predict moderate decrease in Skylark 'preferred' habitats (Table 2.4.). The total habitat of this typical farmland bird species will decrease between 2006 and 2050 is about 1 885 600 ha in Hungary. This suggests that the recent land cover change had an important role in the reported decreasing trend of the Skylark abundance. However, the used statistical method does not allow to estimate quantitatively the further changes of the Skylark population as it may also depend on the level of agricultural intensification.

Table 2.4. The predicted CLC and Skylark habitat changes between 2006 and 2050 in Hungary (according to Farkas & Lennert (Farkas and Lennert, 2015)*).*

Skylark habitat type	Name of the CLC category (code)	Total area in 2006 (1000 ha)	Predicted area in 2050 (1000 ha)	Predicted change between 2006–2050 (1000 ha)	Predicted Skylark habitat change between 2006–2050 (1000 ha)
Preferred	Arable lands (21)	4943.03	4820.21	-122.81	-188.56
	Pastures and grasslands (23)	885.21	796.69	-88.51	
	Permanent crops (22)	228.52	251.28	22.76	
Not preferred	Artificial surfaces (1)	546.08	625.43	79.34	188.56
	Forests (31)	2027.69	2280.37	252.68	
	Heterogeneous agricultural areas (24)	394.71	251.26	-143.45	
	Inland water bodies (51)	262.33	262.33	0	

2.4. Discussion

According to our results the permanent crops (vineyards, fruit trees and berry plantations) CLC categories had a significant positive effect on the Skylark abundance. The arable land category was not analysed, because this is the main well-known habitat of the Eurasian Skylark. We found that, in accordance with the literature, pastures are the typical habitats of the Eurasian Skylark (Cramp, 1988; Hoffmann et al., 2016; Koleček et al., 2015; Nagy et al., 2009) (Table 2.2.). Pastures are exposed to grazing, however moderate grazing intensity does not disturb ground nesting farm- land birds such as the Eurasian Skylark, but it maintains low vegetation and a relatively simple habitat structure. Consequently, these kind anthropogenic disturbances keep the openness of the landscapes in a higher volume than in the pasture areas compared to natural grasslands, resulting in a lack of significant statistical connection of pasture areas with the abundance values of the Eurasian Skylark (Table 2.3.).

The recent land abandonment of grasslands and the increasing cover of dense bushes strongly increases the visual landscape closeness, and may result in a decline in Skylark populations. The most sever decrease in the Skylark habitat occurred in the central and western part of Hungary, where the leading process of the recent land use change were land abandonment and urban sprawl (Szilassi 2015).

We also found negative statistical connections between the extension of 'scrub and/or herbaceous vegetation associations' CLC category (including natural grassland areas) and Skylark abundance. We can explain it with the succession processes of natural grasslands, because these are mostly abandoned arable lands, which nowadays transforming into the scrub areas. This process reduces the openness of the natural grasslands.

The urban built-up areas, forests, inland wet- lands and inland water bodies had a negative effect on the occurrence of the Eurasian Skylark. Gottschalk et al. (Gottschalk et al., 2010) and Berg et al. (Berg et al., 2015) also found negative statistical connections between forest areas and Skylark abundance, but we detected it only inside 300 m and 600 m circle radius around the observation points, while the 'urban fabric' and the 'heterogeneous agricultural areas' had a negative relationship with the Skylark abundance inside all investigated buffer zones. The Skylark is not abundant in these CLC land cover categories, as the increase of these areas results in a decrease in habitat as well as in the population number of the Eurasian Skylark.

The negative effect of forest land cover category can be explained by the dense and relatively high vegetation structure of the forests, which decrease the openness and the visibility of the landscape. Numerous studies emphasise the importance of openness and the land-cover heterogeneity on farmland bird abundance (Gottschalk et al., 2010; Guerrero et al., 2012; Morelli, 2013; Pedersen and Krøgli, 2017). The 'heterogeneous agricultural areas' land cover type of CLC database contains heterogeneous landscapes with diverse mosaics of different land cover types such as small forests and other habitat types mainly not preferred by Skylark. Increasing land-cover het- erogeneity has a negative effect on Skylark abundance (Berg et al., 2015; Gottschalk et al., 2010; Guerrero et al., 2012). Skylark prefers the small-scale heterogeneity of crop structure within an arable field (Miguet et al., 2013), however this species does not prefer the agrarian landscapes with large scale landscape diversity (compositional heterogeneity in regional scale).

The land cover change-based analyses of the recent habitat change of the Eurasian Skylark indicates strong roles of the main landscape changes. Recent afforestation and abandonment of poor-quality agricultural fields, urban sprawl, and increasing trends of landscape heterogeneity resulted in the increase of land cover types not preferred by Skylarks and may be responsible for the recent declining trend of the abundance of this species (Báldi et al., 2005; Báldi and Batáry, 2011b, 2011a; Batáry et al., 2006; Szép et al., 2012; Verhulst et al., 2004). According to our results the habitat loss of the Eurasian Skylark will continue at least until 2050. Because the CLC database is a European level regional land cover database, our results can be adapted to estimate the most recent habitat changes of the Eurasian Skylark in other EU countries, and the presented methods can also be adapted to identify the land cover types that are the habitats of other bird species.

2.5. Conclusion

We identified regional (CLC) land cover categories that have either a positive or a negative impact on the occurrence/abundance data of the Eurasian Skylark. We demonstrated that the abundance conditions of the Eurasian Skylark showed a statistical connection with the characteristics of land cover. On the regional scale (based on the CLC data- base), the proportion of 'pastures' and 'permanent crops' in the MMM buffer zones showed significant positive statistical relationships with the frequency and density data of the Eurasian Skylark. According to our findings, the 'urban fabric', and heterogeneous agricultural areas' are not grain scale dependent variables, which means that its land cover types show negative significant connections with the Skylark abundance in all distances (300 m, 600 m, 1200 m) from the MMM observation points. Our results emphasise the usefulness of the CORINE regional scale database on bird habitat change studies. Since the CORINE database applies a single methodology throughout the EU, the estimation of changes in the area of land cover types may help to estimate the recent- and predict the future changes in the habitats of Skylark and other farmland birds throughout the EU.

3. Density of Biogas Power Plants as An Indicator of Bioenergy Generated Transformation of Agricultural Landscapes

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Abstract

The increasing use of biogas, produced from energy crops like silage maize, is supposed to noticeably change the structures and patterns of agricultural landscapes in Europe. The main objective of our study is to quantify this assumed impact of intensive biogas production with the example of an agrarian landscape in Northern Germany. Therefore, we used three different datasets; Corine Land Cover (CLC), local agricultural statistics (Agrar-Struktur-Erhebung, ASE), and data on biogas power plants. Via kernel density analysis, we delineated impact zones which represent different levels of bioenergy-generated transformations of agrarian landscapes. We cross-checked the results by the analyses of the land cover and landscape pattern changes from 2000 to 2012 inside the impact zones. We found significant correlations between the installed electrical capacity (IC) and land cover changes. According to our findings, the landscape pattern of cropland expressed via landscape metrics (mean patch size (MPS), total edge (TE), mean shape index (MSI), mean fractal dimension index (MFRACT) increased and that of pastures decreased since the beginning of biogas production. Moreover, our study indicates that the increasing number of biogas power plants in certain areas is accompanied with a continuous reduction in crop diversity and a homogenization of land use in the same areas. We found maximum degrees of land use homogenisation in areas with highest IC. Our results show that a Kernel density map of the IC of biogas power plants might offer a suitable first indicator for monitoring and quantifying landscape change induced by biogas production.

Keywords: renewable energies; biogas power plants; silage maize; pasture; landscape metrics; land cover change; landscape diversity; agricultural diversity

3.1. Introduction

In order to lower greenhouse gas emissions, the EU member states intend to add an increasing share of renewable energy sources to their national energy systems. Renewable resources like wind, solar, geothermal, hydropower, and biogas produced from biomass allow the generation of electricity and heat, which contributes to reaching the climate protection goals of the European energy sector (EU, 2009). Currently, energy from biogas, mostly electricity (EEA, 2017), yields 7.6% of primary renewable energy production in the EU. Biogas produced by anaerobic co-digestion of waste and agricultural products like manure and energy crops contributes 69% to this share (European Commission), 2017).

Today, the usage of biogas and biomass to produce electricity is a world-wide applied technology. It is a relevant topic all over the world, as shown by the current studies on sustainable use of crop residues in biogas power plants in the USA (Sahoo et al., 2018), the changes in agriculture systems in East European countries (Di Leo and Salvia, 2017; Van Der Horst et al., 2018), or analysis of straw and manure potentials as feedstock in China (Gao et al., 2019).

Especially in Germany, the introduction of a renewable energy law in 2000 and its amendments in 2004 and 2009 have encouraged a boost in biogas production. This law subsidizes electricity production from renewable energy resources, including biogas. At the time of its implementation, the law guaranteed comparatively high and constant feed-in tariff for new biogas power plants over a 20-year period. It also introduced a bonus for the use of renewable substrate materials like manure and energy crops. For these reasons, a strong increase in the number and installed capacity of biogas power plants took place (Scheftelowitz et al., 2018). In 2014, Germany produced 50% of the total biogas among the EU member states (European Commission), 2017). Most of this biogas is used to generate electricity in more than 10,000 biogas power plants with an installed capacity of over 4,500 MW (Scheftelowitz et al., 2018), which are mainly operated by local farmers. Agricultural residue like manure from cattle and pigs, and energy crops contribute to 97% of the biogas power plants' feedstock, with silage maize (or green maize) (Zea mays L.) as the major crop source material for biogas production (European Commission), 2017).

Silage maize for biogas purposes is currently grown on about 900,000 ha in Germany (AdV, 2017). Younger amendments to the original renewable energy law in 2012 and 2014 slowed down the former rapid development of new biogas power plants (Scheftelowitz et al., 2018). However, several studies state that this energy policy instrument caused many changes in local agricultural systems in different regions of Germany (Appel et al., 2016; Delzeit et al., 2012; Gasso et al., 2015). These include changes in land-use (Laggner et al., 2014; Lüker-Jans et al., 2017), bio-diversity aspects like species composition (Brandt and Glemnitz, 2014; Schleupner and Link, 2008), ecosystem services (Lupp et al., 2014) and landscape structure and functions (Link and Schleupner, 2007).

A central part in the discourse on the agricultural biogas production is the question of whether increased use of biogas for energy production leads to a loss of permanent pasture because of increased silage maize cultivation. Lükers-Jans et al. (Lüker-Jans et al., 2017) postulate a triangle of mutually interacting input factors for this kind of land-use change driven by energy policy. They recommend a future investigation of the correlation between the installed capacity of biogas power plants and the expansion of both maize cultivation area and conversion of pastures. It has to be considered that the silage maize areas located in regions with high livestock density and the livestock density also shows correlation with the biogas power plants (Lüker-Jans et al., 2017). Higher installed electrical capacity means more manure and silage maize needed to feed the biogas power plants. Laggner et al. (Laggner et al., 2014) noted an increase in silage maize area in most communities where pastureland area decreased between 1999 and 2007. Conversion of permanent pasture to grow crops like silage maize is related to increasing risks of soil erosion and compaction (Duttmann et al., 2014, 2011), increasing nitrogen mineralization and leaching (Claus et al., 2014; Klu, 2013; Svoboda et al., 2013), increasing release of greenhouse gases from humus degradation (Klu, 2013) and changes in local bio-diversity (Brandt and Glemnitz, 2014; Klu, 2013; Link and Schleupner, 2007). In addition, the traffic in the proximity to biogas power plants usually increases seasonally due to the large amount of feedstock material transported from the surrounding fields to the power plant site in harvesting time (Duttmann et al., 2013). In Germany a high proportion of biogas power plants were built on already existing farms, instead of installing them on undeveloped land like in the Czech Republic and Italy (Pantaleo et al., 2013; Van Der Horst et al., 2018).
Based on the maps of Schmidt (Schmidt, 2019), in Germany highest shares of silage maize area can be detected in the most northern federal-states of Schleswig-Holstein and Lower-Saxony between 1999 and 2013. Using remote sensing, Oppelt et al. (Oppelt et al., 2012) examined a small catchment in Schleswig-Holstein, and detected local land-use changes that shifted from cereals and permanent pasture to increases in silage maize. They identified areas where intense conversion of pasture occurred over a 3-year period from 2009 to 2011.

Similar results were reported by Kandziora et al. (Kandziora et al., 2014) from the areas in the Central East and the North East of Schleswig-Holstein. Based satellite data they found a decrease in pastureland by about 50% from 1987 to 2007 and complementary increase in cropland at the same time. Areas cultivated with maize grew by 83% (Central East), respectively 249% (North East) over this timespan. Furthermore, crop rotation analyses for the years 2009 to 2011 further showed conversion of pasture in combination with mono-cropping of maize.

Landscape metric parameters are widely used as indicators of biodiversity, water quality and land cover change (Borges et al., 2017; Feng et al., 2018; Schindler et al., 2013; Szilassi et al., 2017; Uuemaa et al., 2013, 2009) and they are still being further developed (Lausch et al., 2015; Šímová and Gdulová, 2012; Weissteiner et al., 2016). They offer a spatial tool set for analysing entire landscapes, as well as the arrangement and properties of their features. These metrics, which originated from the landscape ecology discipline (Turner, 2005, 1989), can provide information about the richness, evenness or fragmentation of a landscapes via quantitative indices. They can indicate, illustrate and quantify the cumulative effects of small changes in land use-patterns, landscape structures and land cover diversity, as well as in landscape functions. Altogether landscape metrics provide quantitative measures for quantifying and monitoring landscape change (Feng et al., 2018; Frondoni et al., 2011; Liu and Weng, 2013; Singh et al., 2015).

Uuemaa et al. (Uuemaa et al., 2009, 2013) stated that more studies should sharpen attention on the impacts of policy instruments on agricultural landscapes. Further, Lausche et al. (Lausch et al., 2015) argued that land-use policies as well as the introduction of new technologies could have a considerable impact on landscape patterns. Based on these contentions, this study focuses on quantifying land use and landscape change processes induced by the intensification of silage maize cultivation for biogas production. We hypothesize that landscape metrics and diversity indicators are suitable for monitoring the impacts of energy policies on the structure and diversity of agricultural landscapes, which are increasingly used for energy production.

To our knowledge no study exists that analyses the transformation of agricultural landscapes as a consequence of increasing biomass production, which utilizes landscape metrics and diversity indices calculated from readily available satellite and topographic data at regional scales. Therefore, the objectives of this study are:

- to delineate the zones of different level of impacts in terms of landscape change by biogas production in agrarian landscapes based on a density map of installed electrical capacity (IC) of the biogas power plants;
- to quantify the impact of biogas power plants via size- and shape- related landscape metrics as well as diversity indices and to investigate the statistical relationships between the IC of biogas power plants and the various metrics.

The main outcome of our study is that we can delineate different impact zones of landscape change based on the installed electrical capacity density of biogas power plants for a federal state in northern Germany. These areas are highly affected by biogas production. We analysed the distribution and changes of land use categories and landscape indices inside of the impact zones to show the usefulness of this method.

3.2. Materials and Methods

3.2.1. Study Area

Schleswig-Holstein, the northernmost Federal State of Germany, serves as the study area. It is surrounded by the Baltic Sea in the east, Denmark to the north and the North Sea to the west (Figure 3.1). The climate is humid with a mean annual temperature of 8.6 °C and mean annual precipitation of 878 mm (weather station Schleswig, 1981–2010, (DWD, 2018)). Schleswig-Holstein has a high level of agricultural use: in 2016, 41.5% of the federal-state's area was arable land, 20.7% pasture, 10.6% forest, 13.2% sealed area and 14% other land cover types (Bundesamt für Kartographie und Geodäsie, 2016).

Based on the geological formations that developed during glacial and Holocene times, Schleswig-Holstein can be divided into four main landscapes from West to East: the "Marschlands", the "Hohe Geest" representing the slightly elevated and eroded remains of terminal moraine tills of the penultimate glaciation (Saalian), the glacial outwash plain ("Vorgeest"), and the "Young moraine hill country" covering the eastern parts of Schleswig-Holstein. The Young Moraine Hill Country is characterized by glacial deposits of the Weichselian glaciation. Parent material for soil development mainly consists of sandy loamy to loamy textures, providing highly fertile soils, such as Luvisols, Cambisols and their stagnic subtypes (according to Food and Agriculture Organization of the United Nations (FAO) (Fao, 2014)). The Young Moraine Hill Country is intensively used for crop production, mainly winter wheat (Triticum aestivum L.), barley (Hordeum vulgare L.) and oilseed rape (Brassica napus L.). In contrast, the sandy deposits of the outwash plain ("Vorgeest" and "Hohe Geest") are characterized by less fertile soils such as Podzols and podsolic Gleysols and frequently wetted Gleysols at deeper positions. While the latter are typically used as meadow and pastureland for livestock farming, the nutrient-poor and water-limited podzolic soils are traditionally cultivated with silage maize (Zea mays L.) and rye (Secale cereale L.) for livestock feeding. The Marshlands on the western part of Schleswig-Holstein have developed since the end of the last ice age. They consist mainly of fine-grained marine sediments with higher shares of silt and clay deposited by the North Sea during the Holocene sea level rise. The younger soils (Calceric Fluvisols/Gleysols) of the Marshlands are highly productive and dominantly used for winter wheat production. The older and frequently wet marshland soils provide less favourable conditions for arable farming and generally used only for pasture.

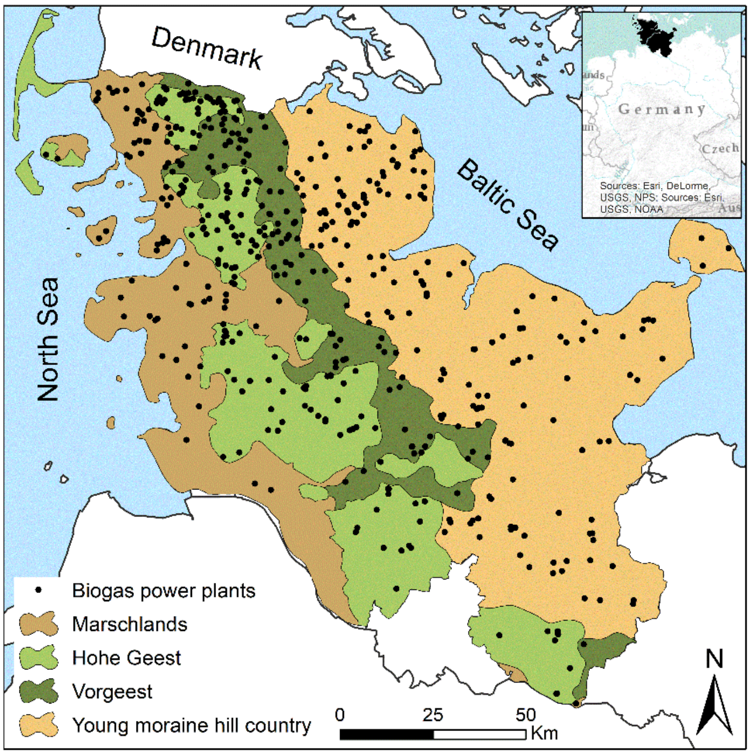

Figure 3.1. The federal state of Schleswig-Holstein in North Germany with main landscape units and biogas power plant sites.

3.2.2. Data Sources and Databases

Small-scale land cover and land-use data for the study site were extracted from the Corine Land Cover (CLC) project data. This data was used to calculate the landscape metric and land cover diversity parameters (Table 3.1.). The CLC data sets are based on satellite image raster data and represent land cover and land-use in Europe at a scale of 1:100,000 at different years. They include 44 classes of land cover and land use, of which 37 are relevant for Germany (EEA and ETC-TE, 2017). A 25 ha minimum mapping unit is used to represent areal unities while linear land cover units are represented with a minimum width of 100 m (Bossard et al., 2000; Bundesamt für Kartographie und Geodäsie, 2016; Szilassi et al., 2017). In this study, CLC data sets for the years 2000 and 2012 were used, because the first biogas power plants were constructed around 2000 and subsequently increased strongly in number until at least 2012.

Statistical data from the German Agricultural Structure Survey (Agrar-Struktur-Erhebung, ASE) was used to calculate land cover and crop diversity metrics on municipality and landscape level (see Table 3.1). This statistical survey is conducted as a full census that gathers data on farm structures and land use as well. For the study region, results from the years 2003 and 2010 were available aggregated at municipality (1106 municipality in Schleswig-Holstein) and at landscape level, provided by the statistical authority. For calculating diversity metrics, the hectares of land-use for crops and pasture were joined to official municipality geodata inside the study area (Bundesamt für Kartographie und Geodäsie, 2016).

Data on the location and installed electrical capacity (IC) of biogas power plants in Schleswig-Holstein were provided by the State Office for Agriculture Environment and Rural Spaces (Landesamt für Landwirtschaft, 2014). The dataset used in this study gives information on 925 sites of biogas power plants from the year 2014 (Figure 3.1), including the characteristics of the generators used to produce electricity from biogas.

We used these three different datasets from five different years as, they are not available for the same year.

Table 3.1. Data sources used in this study (based on (EEA and ETC-TE, 2017; Landesamt für Landwirtschaft, 2014; Statistiches Amt für Hamburg und Schleswig-Holstein, 2010)*).*

	Corine Land Cover (CLC)	**Agricultural structure survey (ASE)**	**Biogas power plants**
Scale	1: 100 000 (> 25 ha)	Municipality level (local scale)	Coordinates of power plant site
Nomenclature	44 classes, 37 relevant in Germany	Every type of agricultural plants and animals	
Used time scales	2000, 2012	2003, 2010	2014
Coverage	Europe	Schleswig-Holstein (Germany)	Schleswig-Holstein (Germany)
Source	Federal Statistical Office	Federal Statistical Office	Federal-state office

3.2.3. Landscape Metrics

Landscape metric parameters are important quantitative implements in landscape ecology (Walz, 2011). The selection of area and shape related landscape metrics used in this work (see below), is based on the work of Szabó (Szabó, 2009) and Walz (Walz, 2011). The software developed by Lang and Tiede (Lang and Tiede, 2003) was employed for the calculation of landscape metrics. Concerning pattern analyses (e.g., (Buyantuyev and Wu, 2007; J.B. Baldwin et al., 2004; Uuemaa et al., 2005; Wu, 2004)), this study uses parameters that are suited to indicate temporal changes in area, structure and diversity at the landscape and patch level (for more details see Appendix 3.4.). Patch level metrics, created for individual land cover patches, characterize the spatial character and context of patches. These patch metrics serve primarily as the computational basis for developing a landscape metric. Class level metrics unify the patches of a given land cover type (class). Landscape level metrics are integrated over all patch types or classes over the full extent of the data. Like class metrics, they may be integrated by a simple or weighted averaging, or may reflect aggregate properties of the patch mosaic.

As many of the available measures of landscape metrics are partially or completely redundant, such as patch density (PD) and mean patch size (MPS), only the MPS was considered in this study. The MPS has been widely applied in landscape monitoring, since it is commonly agreed that the occurrence and abundance of different kinds of species and species richness as well, strongly correlates with the patch size. Amongst patch size metrics, edge-metrics can be used to characterize the spatial grain and the structural variety of a landscape (Turner, 1989). The total edge (TE) of all patches in a selected landscape is known to have several effects on ecological phenomena (Uuemaa et al., 2009). Both of the landscape indicators, MPS and TE, were used to represent the continuity of the landscape's structure during the observed period from 2000 to 2012. The Mean Shape Index (MSI) was calculated to further describe the changes in the geometrical complexity of a patches. The mean fractal dimension index (MFRACT) is a normalized shape index in which the perimeter and area are log transformed (Turner, 1989).

For evaluating changes in landscape and in structural richness, the Shannon diversity (SDI), evenness (SEI) and the richness indexes (RI) according to Uuemaa et al. (Uuemaa et al., 2009) were applied, involving all land use classes in the study area.

To assess the effects of the increasing number of biogas power plants on the landscape patterns' grain size, MPS and TE have been chosen. The effects on the shape complexity of the individual land use types were quantified by using MSI and MFRACT as indicators. We used the area weighted mean (AWM) values of these indices in the statistical calculations. AWM equals the sum of all patches in the area, of the corresponding patch type multiplied by the proportional abundance of the patch and divided by the sum of the patch areas.

3.2.4. Spatial and Statistical Analysis

In order to relate the changes in land cover and land cover pattern to the IC of biogas power plants inside an area we delineated three impact zones of different density of IC (MW km^{-2}) using Kernel Density calculation within ArcGIS 10.3 software (Environmental Systems Research Institute (ESRI), 2014). Separation of the single IC density classes followed the Jenks natural breaks classification method (Jenks, 1967). In detail, three impact zones were defined: "impact zone A" (1.03 to 2.46 MW/ km^2), "impact zone B" (0.3 to 1.03 MW/ km^2), and "impact zone C" (< 0.3 MW/ km^2) (Figure 3.2).

The structural characteristics of land cover and the land cover pattern inside of these impact zones and their changes were analysed using the CLC data sets. AWM values have been calculated based on the class level landscape indices in the three impact zones and in the total study area using the Geospatial Modelling Environment (Beyer, 2014). This tool uses just the patches which having their centroids inside a given impact zone. Area-weighted metrics are more meaningful in ecology than the means as suggested by Gustafson (Gustafson, 1998). Based on CLC data, the area-weighted size (AWMPS), edge (AWMTE) and shape metrics (AWMFRACT, AWMSI) were calculated for the landscape level and the class level (classes are patches of "arable land" and "pastures") considering the individual impact zones and the entire federal-state of Schleswig-Holstein. CLC data sets were also used to calculate the landscape level diversity indices (SDI, SEI and RI) for the three impact zones of the study area. The same indices have been calculated for the municipality level using the ASE data set to detect changes in agricultural diversity (all kinds of agricultural land use) and crop diversity (only crop types) at local scale.

The landscape metrics related to size and shape (AWMPS, AWMTE, AWMFRACT) were calculated using the V-Late 2.0 (Vector-based Landscape analysis tool extension of ArcGIS 10.2) tool (Lang and Tiede, 2003). The same applies for the land cover diversity indices (SDI, SEI, RI) derived from CLC data. For calculating the same agricultural diversity indices from the ASE data-set, a Microsoft Excel add-in (SSC, 2010) has been applied. We calculated the area weighted shape and size related landscape indices, and the averages of the land cover and crop diversity indices for each municipality of the study area. We counted and summarized every biogas power plants and their IC (MW) in every municipality. At the statistical analysis part of the work, we selected the municipalities (containing the metrics and IC values) inside every impact zone and calculated the coefficient value for every impact zone. We ran a one-way analysis of variance (ANOVA) test on our municipality dataset (containing the landscape metrics and diversity indices). This analysis can be performed on a dataset with three or more groups, so the three impact zones were declared as groups. The ANOVA test is a technique to compare the means of groups using F distribution. The null hypothesis is that samples in all groups are drawn with the same mean values. We used the Tukey post hoc multiple comparison, which shows, which groups differed from each other. For statistical analyses between the IC of biogas power plants, and the landscape indices describing the shape and size characteristics of land cover patches, and the land cover diversity, the non-parametric Spearman rank correlation was used. IBM SPSS Statistics 22 software (IBM SPSS, 2013) was used for statistical evaluation.

3.3. Results

3.3.1. Delineation of the Bioenergy Impact Zones

Kernel density calculation enabled the separation of three impact zones of different density of IC of biogas power plants (Figure 3.2). We named the three delineated impact zones based on the density of biogas power plants installed electrical capacity: impact zone A = 1.03–2.46 MW/km^2, impact zone B = 0.3–1.03 MW/km^2, impact zone C = 0–0.3 MW/km^2. Impact zone A is mainly located in the central northern part of Schleswig-Holstein, which is traditionally used for livestock- breeding and milk production. Areas of impact zone B comprise nearly all the interior landscapes, while impact zone C areas occur along the periphery of the federal state.

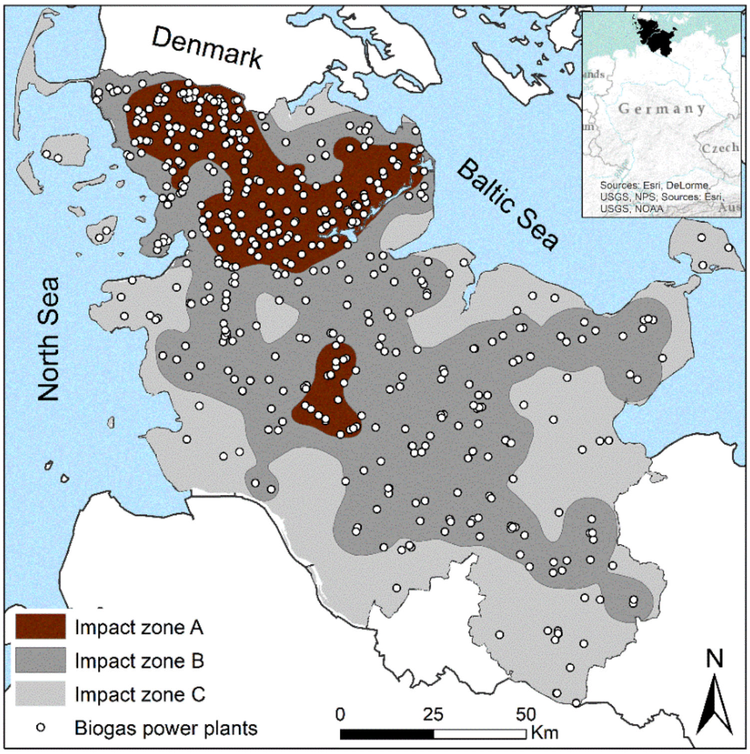

Figure 3.2. Biogas generated landscape transformation impact zones in the study area based on the Kernel density of installed capacity of biogas power plants: impact zone A = 1.03–2.46 MW/km^2, impact zone B = 0.3–1.03 MW/km^2, impact zone C = 0–0.3 MW/km^2 (data source: Agriculture Environment and Rural Spaces 2014 (Landesamt für Landwirtschaft, 2014)*).*

3.3.2. Land Cover Changes Inside the Impact Zones

Based on the CLC data sets from 2002 and 2012 various changes regarding land use can be detected, in the entire study area. The biggest changes relate to the CLC class “non-irrigated arable land” and “pastures” inside the delineated impact zones. According to Bossard et al. (Bossard et al., 2000), the land use class "non-irrigated arable land" refers to land parcels cultivated with annually harvested non-permanent crops, usually grown in a crop rotation. The land use class “pasture” subsumes all permanent grassland characterized by agricultural use, like grazing or harvesting of grass. Regarding the entire study area, the amount of arable land increased by 5%, while the pasture decreased by 1%. Between 2000 and 2012, impact zone A reveals an increase of "non-irrigated arable land" by 17% and a decrease in pasture area by 11%. Inside impact zones B and C, only small changes of a few percent were registered (Appendix 3.1).

Based on the ASE dataset, we analysed the changes in different agricultural land use types for the entire study area. Figure 3.3 shows the changes in silage maize and pastures area. These land use types experienced the greatest change from 2003 to 2010 (Figure 3.3). The Pasture area decreased by 68,000 hectares, while the silage maize acreage increased by 89,000 hectares.

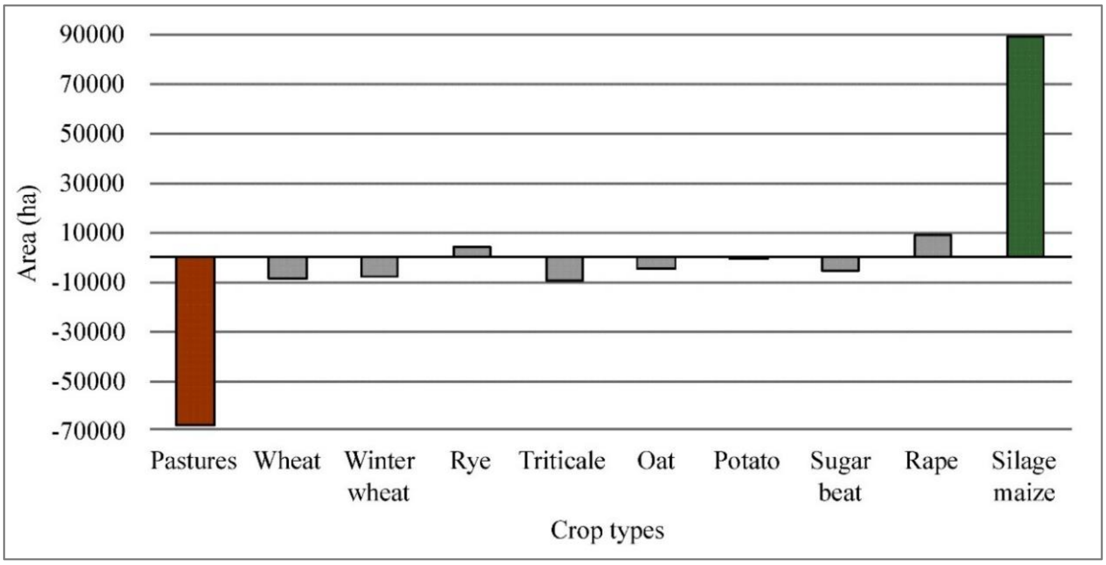

Figure 3.3. Area changes of the different agricultural land use types in federal state of Schleswig-Holstein, based on the German Agricultural Structure Survey (Agrar-Struktur-Erhebung, ASE) 2003 and 2010 datasets.

Correlating the ASE data to the impact zones shows that the proportion of silage maize area strongly increased, mainly inside impact zone A. In some municipalities, the proportion of silage maize amounts to 66% of the total area of agricultural land use (Figure 3.4).

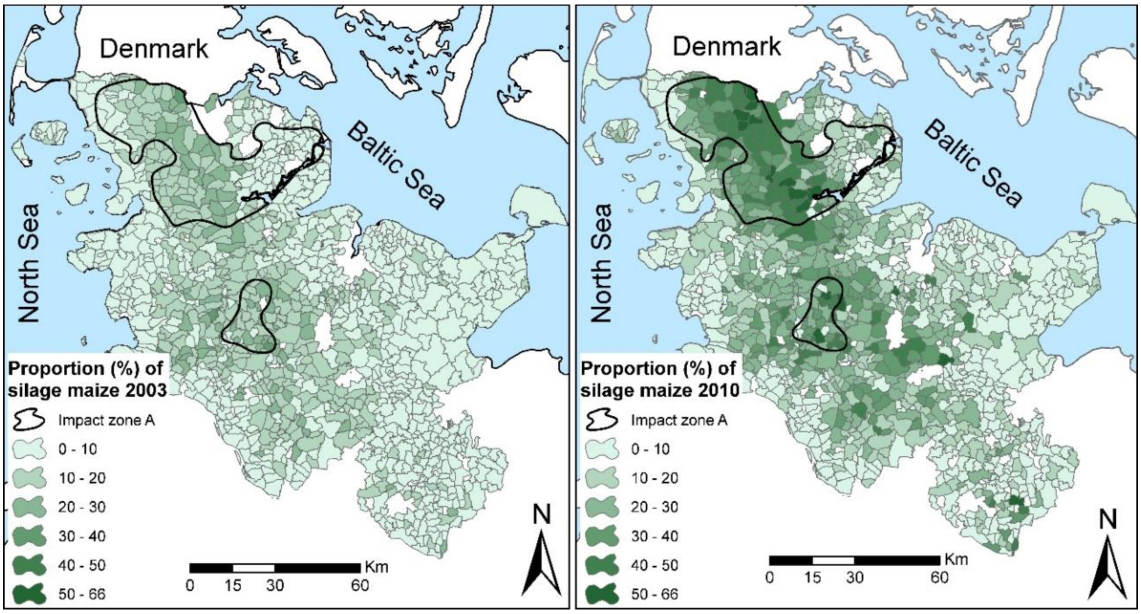

Figure 3.4. The proportion of silage maize areas at municipality level, based on ASE database in 2003 (a) and in 2010 (b).

Compared to the entire state of Schleswig-Holstein, where the silage maize acreage increased on average 9% between 2003 and 2010, impact zone A shows a stronger positive change in silage maize acreage of about 20%. During the same period, the pasture area decreased by the same percentage. The biggest changes in land use appear in the northern parts of the glacial outwash plain (Vorgeest). In contrast, only modest changes occurred in the impact zones C (comparing Figure 3.4a and Figure 3.4b). Furthermore, the ASE data indicate that a large proportion of pasture had been transformed into arable land for silage maize production (Appendix 3.2).

3.3.3. Landscape Metrics Inside the Impact Zones

The effects of increased biogas production on the spatial structures of "non-irrigated arable land" and "pasture" were quantified via a set of area, edge and shape related landscape metrics calculated from CLC data. In general, Appendix 3.3 reveals decreases in size (AWMPS), perimeter (AWMTE) and complexity (AWMSI, AWMFRACT) for the arable land and pastures compared to state wide conditions. Further, the data for impact zone A deviate noticeably from the others. Here, the edge length indicator AWMTE and the complexity indicators AWMSI and AWMFRACT of arable land increased from 2000 to 2012. In contrast, the same indicators for pasture areas show a strong decrease. The patch sizes (AWMPS) of pastures also declined drastically during this period. These findings suggest that patches occupied by cropland became bigger and more complex, while the perimeters of these patches increased relative to area they enclose. For pastureland the opposite trend occurred, as patches became smaller and more compact. Except for the AWMFRACT, which shows an increase for arable land and pastures in the impact zone B and C, all other shape and size related patch level metrics reveal declining values.

3.3.4. Land Cover Diversity Inside the Impact Zones

Land cover diversity indices (RI, SDI and SEI) were calculated from CLC data. They show a decreasing tendency between 2000 and 2012 inside the entire study area. The strongest decline can be observed for the SDI which decreased from 1.207 to 1.067. Furthermore, the SEI changed from 0.403 to 0.356 (Appendix 3.5). Impact zone A is characterized by the smallest SDI and SEI numbers, while the RI does not reflect any changes in these areas.

Moreover, ASE statistics indicate a strong decline in agricultural and crop diversity. The richness index (RI) calculated for agricultural diversity decreased in the individual impact zones as well as in the entire area of the federal state of Schleswig-Holstein (Table 3.2). Strongest reductions of RI occurred in areas of impact zone A, which also revealed the largest negative changes in SDI, while the SEI only varied slightly (Table 3.2).

For crop diversity areas of impact zone A show the strongest change, compared to the entire study area as well as to the impact zones B and C.

Table 3.2. Changes in the diversity indices between 2003 and 2010 for different agricultural land use and crop types based on ASE 2003 and 2010 data sets (IC = Installed electrical Capacity).

	Landscape diversity indices	Impact zones based on their IC density			Entire study area
		Impact zone A	Impact zone B	Impact zone C	
Agricultural diversity	**Richness**	−4.543	−4.009	−3.377	−3.849
	Shannon Diversity	−0.642	−0.56	−0.478	−0.541
	Shannon Evenness	−0.012	−0.014	−0.031	−0.019
Crop diversity	Richness	−1.718	−1.359	−0.955	−1.261
	Shannon Diversity	−0.509	−0.359	−0.241	−0.337
	Shannon Evenness	−0.266	−0.144	−0.091	−0.142

3.3.5. Link between Installed Electrical Capacity (IC) and Changes in Land Use and Landscape Indices in the Impact Zones

There was a statistically significant difference between groups as determined by one-way ANOVA test, non-irrigated arable land: AWMPS ($F(2, 1087) = 27$, $p = 3.57-12$), AWMTE ($F(2, 1087) = 25.6$, $p = 1.35-11$), AWMSI ($F(2, 1087) = 10.89$, $p = 2.07-5$), AWMFRACT ($F(2, 1087) = 0.15$, $p = 0.6$) (Appendix 3.6 and 3.7); pastures land: AWMPS ($F(2, 1087) = 5.94$, $p = 0.003$), AWMTE ($F(2, 1087) = 5.66$, $p = 0.004$), AWMSI ($F(2, 1087) = 5.42$, $p = 0.005$), AWMFRACT ($F(2, 1087) = 4.71$, $p = 0.009$) (Appendix 3.8 and 3.9). According to these results of the ANOVA test, the three delineated impact zone show significant difference in the mean of the landscape indices. The non-irrigated arable land patches' shape and size characteristics show a significant positive correlation ($p < 0.05$) with the IC of each impact zones and the entire area of Schleswig-Holstein, while the same landscape indices for the pasture land cover patches are negatively (but not significantly) correlated with IC. We used just the municipality dataset with IC and ASE data for this calculation.

The tightest positive significant correlations ($p < 0.01$) between IC and AWMPS, AWMTE and AWMSI were measured in case of the "non-irrigated arable land use" patches located inside the impact zone A, while AWMFRACT only shows a weaker, but still significant correlation. Significant positive correlation coefficients were observed at the AWMSI of arable land, while negative coefficients were registered for AWMFRACT ($r = -0.250$, $p < 0.05$) related to pasture land (Table 3.3).

Inside impact zone C, only the AWMPS yields a significant correlation ($r = 0.319$, $p < 0.05$) for arable land use. Inside impact zone B, no significant correlation was found between IC and the single indices.

*Table 3.3. Correlations between the IC and the landscape indices of impact zones based on the Corine Land Cover (CLC) 2012 database (IC = Installed electrical Capacity, AWMPS = Area weighted mean patch size, AWMTE = Area weighted mean total edge, AWMSI = Area weighted mean shape index, AWMFRACT = Area weighted mean fractal dimension index). **= Correlation is significant at p < 0.01 level (2-tailed); *= Correlation is significant at the p < 0.05 level (2-tailed).*

CLC category	**CLC code**	**Shape or size related landscape indices**	Impact zones based on their IC density			Entire study area
			Impact zone A	Impact zone B	Impact zone C	
Non-irrigated arable land	**211**	**AWMPS**	0.269 **	0.033	0,319*	0.128 *
		AWMTE	0.270 **	0.038	0.285	0.139 *
		AWMSI	0.295 **	0.039	0.248	0.144 *
		AWMFRACT	0.260 *	0.008	0.171	0.121 *
Pasture	231	AWMPS	−0.201 *	−0.02	−0.176	−0.056
		AWMTE	−0.216 *	−0.02	−0.167	−0.056
		AWMSI	−0.243 *	−0.012	−0.171	−0.06
		AWMFRACT	−0.250 *	−0.012	−0.246	−0.08
N			97	148	46	291

Based on the ASE dataset we found significant correlations between the different types of agricultural land use and the installed capacity of biogas power plants (Table 3.4). Silage maize acreage strongly positively correlates ($r = 0.572$, $p < 0.01$) with the IC density of the study area as well as with the individual impact zones ($p < 0.01$). Significant correlations were calculated for regions of highest biogas production, while correlations get weaker with a decrease in IC density.

*Table 3.4. Correlations between the IC and different crop types in municipality level, based on Agricultural Statistical Survey 2010 (IC = Installed electrical Capacity). **= Correlation is significant at p < 0.01 level (2-tailed); *= Correlation is significant at the p < 0.05 level (2-tailed).*

Land cover types	Impact zones based on their IC density			Total study area
	Impact zone A	Impact zone B	Impact zone C	
Total agricultural areas	0.562 **	0.428 **	0.183 **	0.397 **
Arable lands	0.541 **	0.394 **	0.152 **	0.365 **
Silage maize	0.572 **	0.389 **	0.238 **	0.462 **
Pasture	0.457 **	0.242 **	0.177 **	0.339 **
Rye	0.254 **	0.194 **	0.013	0.196 **
Fallow	0.216 **	0.153 **	0.082	0.108 **
Wheat	0.182 *	0.235 **	0.133 **	0.137 **
Winter wheat	0.178 *	0.242 **	0.158 **	0.145 **
Barley	0.097	0.140 **	0.123 *	0.085 **
Potato	0.086	0.128 **	0.064	0.054
Winter rape	0.185 *	0.217 **	0.115*	0.119**
Triticale	0.138	0.080	0.170 **	0.076 *
N	160	544	408	1112

There was a statistically significant difference between groups as determined by one-way ANOVA test, SDI (F (2, 1108) = 26.62, p = 5.09−12), SEI (F (2, 1108) = 14, p = 9.98−7), RI (F (2, 1108) = 20.63, p = 1.6−9) (see Appendix 3.10 and 3.11). Based on the ANOVA test the mean values of the diversity indices in the impact zones show significant differences. Finally, significant inverse correlations between the IC of the impact zones and land cover diversity (SDI, RI SEI) can be determined (Table 3.5). Impact zone A shows negative correlation coefficients with the diversity indices, SDI (r = −0,234, p < 0.01), SEI (r = −0.257, p < 0.01) and RI (r = −0.297, p < 0.01). Impact zone C does not correlate with the individual diversity indices. The findings in Table 3.5. suggest a decreasing influence of biogas production on landscape diversity with the decline of IC in a region.

*Table 3.5. Correlation between changes in crop diversity and the Installed electrical Capacity (IC) of biogas power plants, based on ASE. **= Correlation is significant at p < 0.01 level (2-tailed); *= Correlation is significant at the p < 0.05 level (2-tailed).*

Land cover Diversity indices	Impact zones based on their IC density			Entire study area
	Impact zone A	Impact zone B	Impact zone C	
Richness Index	−0.297 **	−0.228 **	−0.094	−0.241 **
Shannon Diversity Index	−0.234 **	−0.098 *	−0.029	−0.137 **
Shannon Evenness Index	−0.257 **	−0.011	0.02	−0.019
N	160	544	408	1112

3.4. Discussion

3.4.1. Comparative Analyses of the Bioenergy Impact Zones

The existing biogas power plants (419 MW installed electrical capacity) in 2014 according to Melund (MELUND, 2018) are mostly concentrated in the central and north-western glacial outwash plain of Schleswig-Holstein (see Figure 3.1), where soils of relatively poor quality dominate and there is a relatively high livestock density. The intensive use of biogas power plants in this area is offering a profitable additional or alternative income to farmers, compared to other common local land-use practices like permanent pasture for dairy farming fodder production. In addition, biogas power plants provide opportunities to process manure, which is available in large amounts in regions of high cattle density (Claus et al., 2014; Delzeit et al., 2012; Klu, 2013; Laggner et al., 2014; Leuschner et al., 2014).

In many cases, fields that were formerly farmed with a diverse crop rotation today possess higher shares of silage maize, especially when they are located in the vicinity of biogas power plants in order to reduce transportation distances and to optimize economic production chains for biomass use (Delzeit et al., 2012; Delzeit and Kellner, 2013; Duttmann et al., 2013; Lüker-Jans et al., 2017). Nevertheless, whether one can directly link locally observed trends of decreasing grassland area and simultaneously increasing silage maize acreage, energy production from biogas is still under discussion. Lüker-Jans et al. (Lüker-Jans et al., 2017) investigated the relation between the expansion of silage maize area, conversion of pasture to arable land and the distance to existing biogas power plants for the Federal State of Hesse in Central Germany, using statistical and farm specific data sets aggregated on municipality level. They found a significant correlation between existing and additional maize area and the distance to biogas power plants and a relationship between the vicinity of biogas power plants and conversion of pasture but also high correlation between existing maize area and livestock density. The proportion of silage maize increased in the entire study area from the beginning of 2000s (Appendix 3.2), and based on the Figure 3.3 it increased by around 90,000 ha, while the pastures had a decrease around 70,000 ha. Figure 3.4 shows the municipalities where the increase was the highest and the silage maize maximum proportion reached the 66%. The expansion of the silage maize was most dynamic in the impact zone A. One can say that silage maize is probably the most significant indicator of the bioenergy generated transformation of the agricultural landscape.

The area of silage maize reveals a positive correlation ($r = 0.572$; $p < 0.01$) with the IC of biogas power plants and the strongest correlation compared to all other types of agricultural land use and arable crops (Table 3.4). The decrease in pasture area coincides with the start of increased silage maize growing. According to the ASE data set other crop and land use types did not increase to that proportion as silage maize did. For a small catchment in Germany Kandziora et al. (Kandziora et al., 2014) could prove the same results that the pasture area decreased to 50% from 1987 to 2007. The statistical analysis in our study make obvious that the silage maize acreage as well as the area of arable land ($r = 0.541$) and pasture ($r = 0.457$) significantly correlate ($p < 0.01$) with the density of IC (Table 3.4). Silage maize is the most common crop used for feeding the fermentation tanks. Interestingly, we found that the pasture area also positively correlates with IC. One reason might be that the farmers use the sown grass as a substrate for biogas production. According to Auburger et al. (Auburger et al., 2017), the harvesting of pastures for biogas power plants could be an alternative way to replace silage maize to a limited degree, however this process is more expensive, so that farmers usually prefer the use of silage maize and manure for biogas production.

3.4.2. Statistical Analysis of the Landscape Metric Parameters in the Bioenergy Impact Zones

Comparing the two CLC data sets from 2000 and 2012 reveals that the patches of arable lands became larger and complex, while the patches covered with pasture became more compact, including a reduced length of their margins/edges. This holds especially true for those regions that have a high density of installed biogas power plants. These findings indicate that a higher percentage of arable fields become interconnected, grow in size and become more complex in shape, while a lesser number of isolated patches of pasture remains (Appendix 3.3). These results fit to the work of Leuschner et al. (Leuschner et al., 2014), who showed for Schleswig-Holstein that from 1950 on the arable lands - and in the last decade the silage maize fields - were getting bigger with a more complex shape, while pastures were getting smaller, more fragmented and isolated.

As shown for the arable land located in the impact zone A, the AWMSI needs to be carefully interpreted and not decoupled from other indices, such as the AWMPS or AWMTE. A higher degree of compactness is not necessarily equivalent to a decrease in patch size or a reduction of edge lengths. The situation mainly depends on the shape of the patches. In arable land patches with noticeable increases in AWMTE and also in complexity as indicated by AWMFRACT (Appendix 3.3), the degree of compactness can also increase, for example, when the field plots are expanded to all sides and have more or less equal widths and length ratios.

The significant positive correlation between the IC and the area of arable land in impact zone A occurs because of the higher demand for silage maize, which is associated with increases in patch size and complexity within the landscape. In contrast, all landscape metrics indicators calculated for the pasture land use type reveal a significant inverse correlation with biogas production intensity. In the case of arable land, the AWMSI shows highest correlation with the IC density of biogas power plants, suggesting that an increase in IC, mainly affects the shape and complexity of the cropland patches. From the indices derived for pasture land, the MFRACT is most strongly correlated to IC inside the impact zone A, implying that the intensity of biogas production contributes mainly to the form of patches, coupled with a higher fractioning of grassland patches, as indicated by the negative significant correlation between AWMSI and IC density. In the impact zone A the AWMSI and AWMFRACT could be an indicator of the bioenergy generated transformation of agricultural landscapes, and they could help identify of this transformation. Uuemaa et al. (Uuemaa et al., 2013) found that these are the most relevant metrics to describe landscape complexity and fragmentation, also for effect on species diversity.

3.4.3. Land Cover Diversity Changes in the Bioenergy Impact Zones

Land cover diversity indices were calculated from the CLC and ASE datasets, and we used the three most common diversity indices (Morris et al., 2014). Regarding changes in landscapes and agricultural diversity, the RI index negatively and significantly correlated to the intensity of biogas production, and compared to all other diversity indices it has the highest negative correlation coefficient. The correlation between the RI and the IC density of biogas power plants is significant ($r = -0.297$, $p < 0.01$, Table 3.5), suggesting the RI to be a suited indicator to identify the bioenergy generated transformation in agricultural used areas (Brandt and Glemnitz, 2014; Lüker-Jans et al., 2017).

Calculation based on CLC data shows the smallest values for SDI in the impact zone A and the strongest decrease of RI compared to the other regions (Table 3.5). The same correlation holds true for SDI, indicating an increase in unevenness related of the different land use classes and crop types, as arable land is increasingly used for silage maize growing at a higher area percentage, including a higher share of maize monoculture. These support the knowledge from regional studies concerning the recent development in “energy landscapes” of Schleswig-Holstein, stating biogas production as the main driver of the landscape and land use change (e.g., (Duttmann et al., 2011; Riedel, 2013)).

A decreasing trend in agricultural land cover diversity can be demonstrated by comparing the ASE data from 2003 and 2010, where most of the biogas power plants were newly constructed. As already described for the CLC data set, the strongest decline in SDI and SEI numbers goes along with the increase in IC density, where the smallest numbers of these indicators are typical for those regions with the highest densities of biogas generated electricity (Appendix 3.5). Regarding the arable land, however, there is a strong increase in the proportion of silage maize, while other agricultural land use types changed by a few percent. Considering crop diversity, a negative change of SDI, SEI and RI can be observed for all impact zones, with the strongest decline occurring in the impact zone A (Table 3.2). This indicates that the increase in silage maize production subsequently replaces other crops originally grown in these

landscapes to a higher degree, which contributes to a loss of crop diversity and a depletion of landscape diversity. These results fit to the work of Jerrentrup et al. (Jerrentrup et al., 2017).
In order to prevent the undesired effects of land cover pattern change and landscape diversity decrease caused by the bioenergy-generated transformation of agricultural landscapes, landscape metrics and diversity indicators generated from data of various spatial scales can support a well-informed approach to landscape management. As shown in this study, spatial landscape metrics and diversity indicators are suited to spatially detect changes in land cover and crop diversity and in the landscape's structure. In this example, landscape metrics have demonstrated that an uncontrolled bioenergy-generated transformation (expansion of maize cropping) may negatively affect landscape diversity.

3.5. Conclusions

This study shows that changes in land use, land cover pattern and landscape diversity caused by a bioenergy-driven transformation of agricultural landscapes can be identified via landscape metrics and diversity indicators applied to readily available data with different degrees of spatial and thematic aggregations. It reveals that the fostered production of electrical energy by biogas power plants can negatively affect the sizes and shapes of former pasture lands and increases the area, size and complexity of arable land patches. Moreover, for the study area in Northern Germany, the application of a Kernel density analysis based on data on the installed electrical capacity (IC) of biogas power plants could spatially identify the main impact zones (hot spots) of biogas energy generated declining land cover and crop diversity. Furthermore, this study provides quantified data on the spatio-temporal changes in landscape metrics indicators related to the different intensity zones of bioenergy generated landscape transformation. According to our findings, the Kernel density map of the electrical capacity of biogas power plants are representing the impact zones of the biogas energy introduction. The calculations based on the Corine Land Cover database can be replicated in the countries of the European Union, where the CLC database exist, but other land cover or land use dataset can be adapting. The GIS tools used, released under general public licence (GPL), therefore are free to use for anyone, with the exception of Environmental Systems Research Institute (ESRI) ArcGIS, which is proprietary. The quality of calculated outcomes could be improved with the availability of remote sensing data of higher spatial and spectral resolution, and of a higher recovery rate, enabling a more detailed classification of land use and crop type, as shown by, for example, Kuhwald et al. (Kuhwald et al., 2018).

4. Impact of Energy Landscapes on the Abundance of Eurasian Skylark (Alauda arvensis), an Example from North Germany

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Abstract

The increasing use of biomass for energy production is reshaping landscapes into energy landscapes. Our study aims to analyse the impact of the biogas energy landscape on the abundance of Eurasian skylark. The biogas power plants have a high impact on the landscape, because of the energy crops like silage maize and rape. We analyse land-use and land-cover heterogeneity in connection with this bird species in the Federal State of Schleswig-Holstein. Three databases are used: abundance data of a typical farmland bird (Eurasian skylark), Corine land cover, and statistical land-use data from the German Agricultural Structure Survey. Several spatial analyses and statistical analyses were conducted. Generalized linear models are used with model averaging and predicted marginal effects were calculated. We estimate the changes in individuals per km^2 by considering six crop types and the Shannon Diversity Index (SDI). The Eurasian skylark abundance has a significant negative correlation with the area of the inland wetlands, the Shannon Diversity Index (SDI), permanent crops, silage maize, and rape. We found significant positive correlation with the pasture, potato, and wheat. The replacement of pastures, Eurasian skylarks' preferred habitat, with energy crops, mostly silage maize, and the ongoing homogenization of the landscape, negatively affected this species' distribution in the study area.

Keywords: energy landscape; Eurasian skylark; land cover; land use; land-cover heterogeneity; crop heterogeneity

4.1. Introduction

Today, the usage of renewable energy sources is a common practice worldwide. Various renewable energy sources can be found in many countries, from the USA to China and across Europe (Gao et al., 2019; Sahoo et al., 2018; Van Der Horst et al., 2018). Alternative energy systems are shaping the landscape, giving birth to a new term, energy landscape. Examples of ways in which these energy systems are changing the landscape include the wind turbines near the coast, biogas power plants in agricultural areas, and solar panels near roads. According to Calvert et al. (Calvert et al., 2019), an energy landscape is defined as an area whose geomorphology is associated with a distinct type of energy production system, nowadays mainly renewable energy. Similar to other landscapes, they are also spatially and temporally dynamic.

The European energy sector has set up its own climate protection goals regarding greenhouse gas emissions. The European Union (EU) members decided to add more renewable energy sources to their national energy systems. The renewable energy production yield from biogas, mostly electricity (EEA, 2017), is 7.6% in the EU. The anaerobic co-digestion of waste and agricultural products, such as energy crops and manure, contributes to 69% of the biogas production (European Commission 2017).

Germany produces half of the total amount of biogas energy in the EU (European Commission 2017). Most of the biogas is used to generate electricity, owing to the introduction of a renewable energy law in 2000, which was amended in 2004 and 2009 to encourage a boost in biogas production (Scheftelowitz et al., 2018). The law guarantees a high and constant feed-in tariff for new biogas power plants. It introduced a bonus for the use of renewable substrate materials, such as energy crops and manure (Scheftelowitz et al., 2018). More than 10,000 biogas power plants are operated mostly by local farmers with an installed capacity of 4500 MW (Scheftelowitz et al., 2018). The transformation from agrarian landscape to energy landscape has many consequences, mostly caused by the energy crop production. The changes generated by the adoption of biomass energy can be observed in ecosystem services (Lupp et al., 2014), biodiversity (fauna and flora) (Brandt and Glemnitz, 2014; Schleupner and Link, 2008), land use (Csikos et al., 2019; Laggner et al., 2014; Lüker-Jans et al., 2017), and landscape structure (Csikos et al., 2019; Link and Schleupner, 2007). The cultivation of pastures and cereals to silage maize is related to increased risk of soil erosion (Duttmann et al., 2011), nitrogen mineralization (Klu, 2013; Svoboda et al., 2013), and release of greenhouse gases (Klu, 2013), as well as to changes in local biodiversity (Brandt and Glemnitz, 2014; Link and Schleupner, 2007). Usually, the transformation from agrarian landscape into energy landscape causes changes in landscape (land cover and land use) heterogeneity.

To analyse the links between the Eurasian skylark and land-cover and land-use (crop) heterogeneity change, we need to first investigate the cause of these changes, which is the establishment of biogas power plants and the energy crop production, like silage maize and rape. Between 2002 and 2012, in Schleswig-Holstein, there was a significant change in the landscape. The landscape transformation changed mainly food-producing landscapes to energy landscapes (Csikos et al., 2019). This relatively fast and significant change in the landscape, as well as its impacts on biodiversity, crop heterogeneity, and the abundance of farmland birds, has not been clarified yet (Csikos et al., 2019).

It is important to investigate the effects of land use, land cover, crop heterogeneity, and crop structure change on the abundance of farmland birds, because many studies have indicated that the abundance of farmland birds in Europe is significantly connected with the intensity of agricultural cultivation, crop heterogeneity, and land-use change (Gil-Tena et al., 2015; Gottschalk et al., 2010; Guerrero et al., 2012; Moreira et al., 2005; Verhulst et al., 2004). The Eurasian skylark Alauda arvensis is the most common farmland bird in Europe, and is also found in the Americas, Australia, and New Zealand (Cramp, 1988). It always nests on the ground and also spends lot of time in the air (Donald et al., 2001).

So far, just a few papers have investigated the Eurasian skylark in the Federal State of Schleswig-Holstein. No studies have analysed the link between the Eurasian skylark abundance and the energy landscape generated by landscape transformation. Therefore, the following are the objectives of this study:

- To analyse the relationship between the abundance of Eurasian skylark, the land-cover and land-use (crop) types.
- To analyse the statistical connection between the Eurasian skylark and landscape heterogeneity by the Shannon Diversity Index (SDI).

The results of this study are expected to be valuable in analysing and forecasting the changes in the abundance of a farmland bird species generated by biomass energy production in a typical energy landscape (North Germany). Moreover, our findings could be used as a guide for studying other situations or can be a useful tool for studying the impacts of energy-landscape-generated land-cover changes on biodiversity in other study areas.

4.2. Materials and Methods

4.2.1. Study Area

The study area is Schleswig-Holstein, the northernmost Federal State of Germany. It is bordered by the North Sea in the west, Denmark to the north, and the Baltic Sea to the east (Figure 4.1). The climate is formed by the sea; it is humid with an average annual precipitation of 878 mm and a mean annual temperature of 8.6 °C (weather station Schleswig, data for 1981–2010, Deutscher Wetterdienst (DWD) (DWD, 2018)).

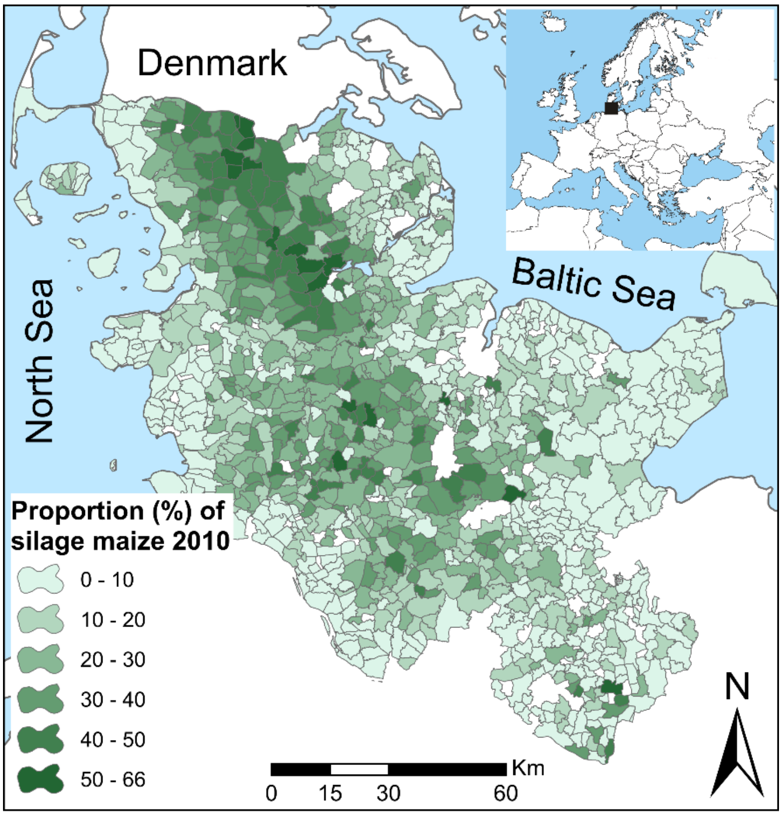

Figure 4.1. Proportions of the typical energy crop (silage maize) in the settlements of Schleswig-Holstein, based on Csikos et al. (2019)

Schleswig-Holstein can be divided into three main landscapes. Marshlands have developed since the end of the last ice age, and these younger soils (calceric fluvisols/gleysols) are highly fertile (Fao, 2014). The outwash plains ("Vorgeest" and "Hohe Geest") are characterized by less productive soils, such as podzols and podsolic gleysols. The Younger Moraine Hill Country area is mainly used for crop production of winter wheat (Triticum aestivum L.), barley (Hordeum vulgare L.), and oilseed rape (Brassica napus L.).

In Germany, the greatest production of silage maize is achieved in the northern federal states of Lower-Saxony and Schleswig-Holstein (Schmidt, 2019). Table 4.1 and Table 4.2 show the proportion of the land-cover and land-use types in Schleswig-Holstein.

Table 4.1. Proportion of the different land-cover types in Schleswig-Holstein, based on Corine Land Cover (CLC) 2006.

CLC Code	Name of the CLC Category	Proportion
11	Urban fabric area	6.46%
12	Industrial, commercial and transport units	1.02%
13	Mine, dump and construction sites	0.38%
14	Artificial, non-agricultural vegetated areas	0.55%
21	Arable land	42.62%
23	Pastures	21.14%
24	Heterogeneous agricultural areas	11.46%
31	Forests	10.67%
32	Shrub and/or herbaceous vegetation associations	0.89%
33	Open spaces with little or no vegetation	0.30%
41	Inland wetlands	1.06%
42	Coastal wetlands	0.29%
51	Inland waters	3.10%
52	Marine water	0.13%

Table 4.2. Proportion of the different crop types from the total agricultural land area in Schleswig-Holstein, based on the German Agricultural Structure Survey (Agrar-Struktur-Erhebung, ASE) 2010 database.

Crop Types	Proportion
Silage maize	17.64%
Wheat	20.68%
Pasture	31.53%
Winter rape	11.24%
Rye	2.05%
Permanent crops	0.67%
Potato	0.55%
Sugar beet	0.75%
Triticale	0.64%
Other	14.25%

4.2.2. Data Sources and Databases

Land-Cover Database

The European Corine land-cover (CLC) maps have been prepared using the same methodology for all EU countries (EEA, 2006; EEA and ETC-TE, 2017). The scale of the maps is 1:100,000, and the minimum mapping unit is 25 ha for land-cover patches with at least 100 m width for linear landscape elements. Mapping is repeated every six years, and thus, three assessments of land cover are available since 2000. They include 44 classes of land cover and land use, 37 of which are relevant for Germany (EEA, 2006) (Appendix 4.1). The study area contains 14 (level-2) CLC categories. We used the CLC dataset from 2006, because the bird field survey data was collected between 2005 and 2009 (Ornithologische Arbeitsgemeinschaft für Schleswig-Holstein 2009).

Land-Use Database

The German Agricultural Structure Survey (Agrar-Struktur-Erhebung, ASE, Hamburg, Germany 2010 was used to investigate the correlations among the Eurasian skylark abundance, land use, and crop types. This statistical survey obtained full census data on crop types and land use (Appendix 4.2). We used the census data from 2010, which were aggregated by municipality (1106 municipalities in Schleswig-Holstein).

Eurasian Skylark Abundance Data

Eurasian skylark abundance data were collected by the ornithological working group of Schleswig-Holstein and Hamburg (Ornithologische Arbeitsgemeinschaft für Schleswig-Holstein und Hamburg). The survey was supported by the ADEBAR (Der Atlas Deutscher Brutvogelarten) project between 2005 and 2009. Around 150 surveyors mapped all the breeding bird species in Schleswig-Holstein. The survey was conducted using the TK25 border grid (11 × 11 km^2), where the area of one grid cell is around 120 km^2 (Südbeck et al., 2005). Each TK25 grid cell was divided into four quadrants with a size of 5.5 × 5.5 km^2 each (Brendt et al., 2005). The federal state of Schleswig-Holstein has 646 TK25 quadrants, of which 380 quadrants were mapped (59%). We used 281 quadrants, which had the latest abundance data from 2009 (Figure 4.2). We used data just from 2009, because this year fits the best to the CLC land cover (2006) and the agrarian census database from 2010.

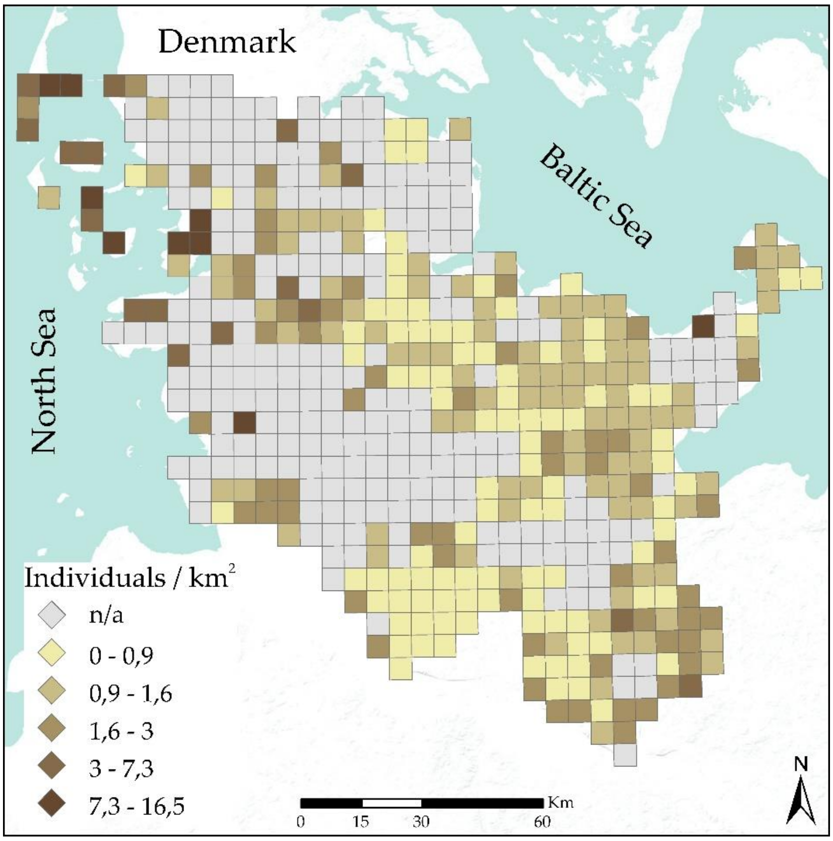

Figure 4.2. Density of Eurasian skylark populations in Schleswig-Holstein. Data source: Ornithologische Arbeitsgemeinschaft für Schleswig-Holstein, 2009.

4.2.3. Spatial and Statistical Analyses

For the spatial analyses, we used the ArcMap module of the ArcGis 10.3 software package. (ESRI, Redland, CA, USA) Following Uuemaa et al. (Uuemaa et al., 2009), SDI was applied to evaluate the connection between the Eurasian skylark abundance and the landscape structure. Land cover and the crop heterogeneity index (SDI) inside the municipality polygons in ASE were calculated using a Microsoft Excel add-in (SSC, 2010). The SDI represents the number of different land-use types and the relative abundance:

$$SDI = -\sum_{i}^{m}(P_i * \ln(P_i))$$

where (m) represents the number of different land-cover types, P_i = the relative abundance of different land-cover types.

For the statistical analysis, we used the grid of the Eurasian skylark abundance data, the municipality layer from the ASE. We joined with the grid quadrants the municipality polygons whose centers were inside the bird survey quadrant. We conducted preliminary tests to identify any correlation between the skylark abundance and the explanatory variables, using the variance inflation factors (VIFs). The explanatory values that were not linearly connected were between VIF value of 0.44 and 8.89. We used generalized linear models (GLMs) to evaluate the effects of land-cover and land-use heterogeneity on the abundance data of Eurasian skylark (ESA). We set the skylark abundance as the response variable and the total area (ha) of the following land-use (crop) categories from ASE as explanatory variables: pasture, rape, silage maize and wheat, permanent crops, sugar beet, rye, and triticale. We used negative binominal models to take into account any overdispersion of the abundance data. We created models with all possible variations of explanatory variables, and used Akaike's information criterion to rank them with the “dredge” function from the “MuMIn” package in R (Barton, 2015). We achieved model averaging for competitive models (delta AICc < 2) by including the uncertainty arising from the high number of candidate models, as proposed by Burnham and Anderson (Burnham and Anderson, 2002). We used the “LmerTest” package to estimate the significance of the variables.

The function ggpredict from the “ggeffects” package (Lüdecke, 2018) was used to compute the predicted marginal effects of the various crops based on the crops’ heterogeneity in the population data of Eurasian skylark. The proportion of the crop types (ASE) and the number of skylarks per square kilometer were calculated inside the bird survey quadrants.

4.3. Results

4.3.1. Correlation Between Land Cover, Land-Use Types and ESA

We correlated ESA and the different CLC categories. Table 4.3 shows a summary of only the significant relationships. In the entire study area, four CLC categories show significant positive relationships with the Eurasian skylark abundance: categories of pasture land, shrub and/or herbaceous vegetation associations, and coastal wetlands. On the other hand, the skylark population is negatively correlated with the inland wetlands. The relationships with the heterogeneous agricultural areas, the inland wetlands, and the urban fabric categories are negative. SDI is negatively correlated with the Eurasian skylark population data in the entire study area (85% importance).

In the entire study area, we observed three positive relationships with land-use types, pasture, potato, and wheat (Table 4.3). There are also three negative relationships, with permanent crops, silage maize, and rape. SDI has a negative relationship with ESA in the entire study area.

*Table 4.3. Summary table for the CLC categories, land-use types and Shannon Diversity Index (SDI), which shows the generalized linear model (GLM) results after multimodel averaging of the best candidate models, showing the relative importance of each explanatory variable on the skylark abundance based on the estimated parameter values ± the standard deviation. Significance levels: *: < 0.05, **: < 0.01, ***: < 0.001.*

Land Cover, Land Use, or Landscape Heterogeneity Variables		**Unit**	**Relative Importance (z Value)**	**Multimodel Estimate ± Standard Deviation**
Land Cover (CLC Types)	Pastures	area in quadrant	100% (5.194)	0.0005 ± 0.0001***
	Shrub and/or herbaceous vegetation associations	area in quadrant	100% (5.387)	0.0024 ± 0.0004***
	Coastal wetlands	area in quadrant	100% (4.625)	0.0017 ± 0.0004***
	Inland wetlands	area in quadrant	100% (3.071)	−0.0024 ± 0.0008**
Landscape heterogeneity	SDI	value	85% (2.104)	−0.2371 ± 0.1127*
Land Use (ASE crop types)	Pasture	area in quadrant	100% (4.322)	0.0005 ± 0.0001***
	Permanent crops	area in quadrant	100% (7.254)	−0.0061 ± 0.0008***
	Silage maize	area in quadrant	100% (2.185)	−0.0004 ± 0.0002*
	Potato	area in quadrant	89% (1.991)	0.0065 ± 0.0033*
	Wheat	area in quadrant	87% (2.239)	0.0005 ± 0.0002*
	Rape	area in quadrant	87% (2.359)	−0.0010 ± 0.0004*
Crop heterogeneity	SDI	value	100% (2.073)	−0.3940 ± 0.1415*

4.3.2. Predicted marginal effects of different crop types and heterogeneity on the population data of Eurasian skylark

The predicted marginal effects of different crop types on the ESA in the entire study area are summarized in Figure 4.3. Each graph in Figure 4.3 shows a narrow confidence interval at the beginning, which widens gradually. According to Figure 4.3A, a maximum of 10 individuals/km^2 is predicted within 90% of the pasture proportion. Silage maize (Figure 4.3C) and the winter rape (Figure 4.3F) both have strong negative impacts on the Eurasian skylark population. On these two graphs, the upper confidence value stagnates or slightly decreases. The predicted marginal effect of the proportion of wheat on Eurasian skylark/km^2 increased almost linearly from 1.4 to 2.8 with a tight confidence interval until the 15% proportion of wheat.

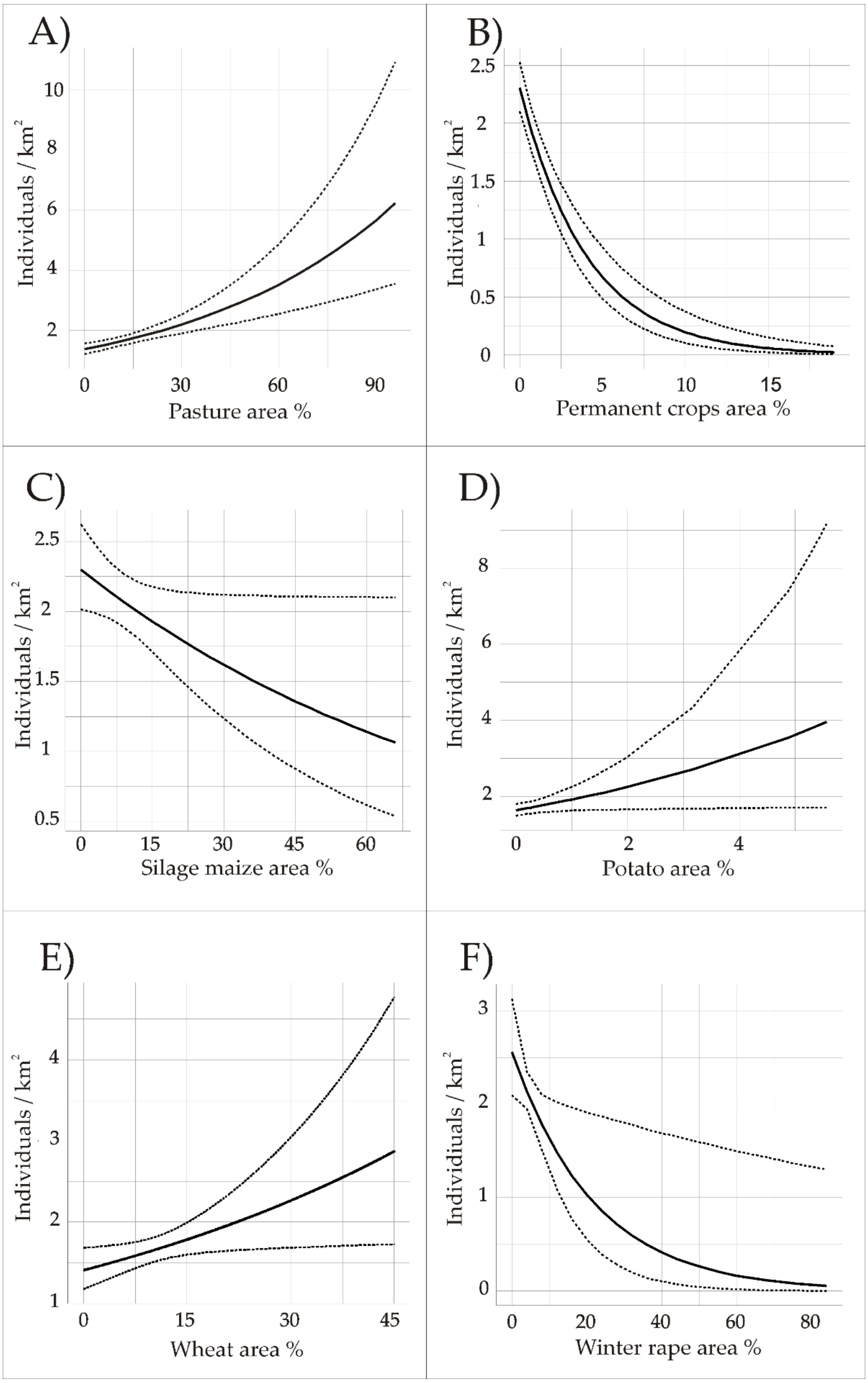

Figure 4.3. Predicted marginal effects of the different crop types on the population data of Eurasian skylark. The confidence intervals (95%) of the prediction are shown between the dotted lines. (A) Pasture area %; (B) Permanent crops area %; (C) Silage maize area %; (D) Potato area %; (E) Wheat area %; (F) Winter rape area %

The predicted marginal effects of SDI on the ESA in the entire study area are summarized in Figure 4.4.

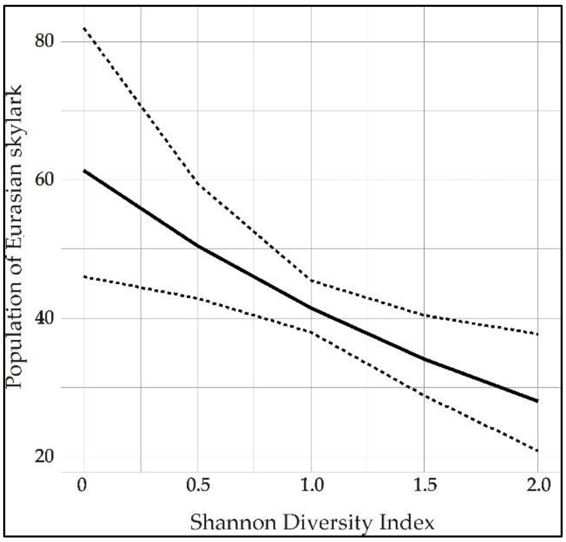

Figure 4.4 Predicted marginal effects of SDI on the population data of Eurasian skylark. The confidence intervals (95%) of the prediction are shown between the dotted lines.

4.4. Discussion

The GLM results for the entire study area show a significant correlation with four land-cover categories. The pasture and the shrub and/or herbaceous vegetation association categories show a positive significant relationship. This is expected since pasture is a typical habitat of the Eurasian skylark (Cramp, 1988; Hoffmann et al., 2016; Peter Szilassi et al., 2019). The positive correlation with the shrub and/or herbaceous vegetation category is more interesting. Szilassi et al. (Peter Szilassi et al., 2019) found a negative connection between this CLC category and ESA data, which they attributed to the succession process of natural grasslands. This category contains natural grassland, hedgerows, shrubs, and low vegetation. Hedgerows can be found at the edges of arable or pasture lands in Schleswig-Holstein. According to Morelli (Morelli, 2013), marginal vegetation types (hedgerows, isolated tree, and uncultivated patches) are rather highly important as a habitat for the Eurasian skylark. We found that the coastal wetland category has a significant positive correlation with skylark abundance in the entire study area. Coastal wetland contains two subcategories in Schleswig-Holstein: salt marshes and intertidal flats. Salt marshes can be a suitable habitat for the skylark, because they include salt pastures and meadows. This result can also be explained by the data scale; the 5.5×5.5 km^2 quadrants can contain both a high proportion of arable land and coastal wetland in the same quadrant. This new biogas energy landscape has a strong effect on the recent land-use/land-cover changes. Due to the introduction of bioenergy plants (especially the silage maize), the area of pastures has been decreased dramatically (Lüker-Jans et al., 2017). Parallel with this process, the landscape heterogeneity also changed because of the fusion of the small parcels into homogeneous large silage maize fields without shrubs and natural grassland corridors.

We found a negative significant correlation between SDI and ESA. Our results confirm that, at the regional (CLC) scale, the increasing landscape heterogeneity has a negative effect on the population of the Eurasian skylark (Berg et al., 2015; Gottschalk et al., 2010; Guerrero et al., 2012; Redlich et al., 2018; Peter Szilassi et al., 2019). The increasing heterogeneity results in a lower abundance of the Eurasian skylark.

Based on the ASE database, we analyzed the relationship between agricultural land-use (crop) types and ESA on a large scale. The establishment of pastures has had a positive effect on the abundance of the Eurasian skylark. We found a negative correlation with the permanent crops category and this category takes the second place in the model, and therefore, has a significant impact on ESA. This negative correlation is probably due to the height and coverage of the vineyards and fruit plantations, which are not suitable habitats for this bird species (Hoffmann et al., 2018; Praus and Weidinger, 2015). In the literature, wheat is a well-known habitat type of the skylark (Hoffmann et al., 2018, 2016; Morris et al., 2004; Praus and Weidinger, 2015). We found a positive significant correlation between wheat and ESA. Silage maize is the next most important crop type of the study area, which also has a negative effect on ESA. We also found a negative correlation between winter rape and the Eurasian skylark in the entire study area. Strong negative impact of silage maize and winter rape can be explained based on the results of Hoffmann et al. (Hoffmann et al., 2018). According to these authors, these fields can provide a suitable habitat for the Eurasian skylark during the early breeding period, but later, these plants will grow too high and the ground coverage will be too much, and this area will not be suitable in the breeding periods of the year. Winter rape has the strongest negative effect, according to our multimodel estimate. The silage maize and winter rapes are the dominant land-use types of the energy landscapes. Based on Csikos et al. (Csikos et al., 2019), there is a significant positive correlation between the capacity of the biogas power plants and the area of silage maize and rape.

The high heterogeneity of agricultural land, i.e., the crop types, also has a negative effect on this bird species. We found significant negative correlations in the entire study area. The relationship between crop heterogeneity and ESA has been analyzed in some previous studies. According to Chamberlain et al. (Chamberlain et al., 1999), in England, the skylark density increased with habitat heterogeneity; nevertheless, farmland plots in the lowlands of England showed decreased skylark density with increasing habitat heterogeneity. These results suggest that the crop type is more important than the crop heterogeneity value (Redlich et al., 2018). According to Blaschke et al. (Blaschke et al., 2013), an increase in cultivation of bioenergy crops inside the biogas energy landscape will decrease the land availability for traditional agriculture and nature conservation.

The predicted marginal effect values are calculated based on the entire study area. Permanent crop has the largest negative effect on ESA and it can decrease the skylark individuals/km^2 value. The wheat area is a well-known habitat of the Eurasian skylark and the predicted values show that an increasing proportion of the wheat area in the landscape can increase the skylark individuals/km^2 value. The confidence interval for potato shows that potato can increase or maintain a constant individuals/km^2 value. Piha et al. (Piha et al., 2003) found that the Eurasian skylark avoided potato, and in larger open farmland areas, the skylark population density was negatively correlated with the proportion of the potato crop area. According to Dietzen et al. (Dietzen et al., 2014) and Kragten et al. (Kragten et al., 2008), potato fields are a suitable habitat for the Eurasian skylark, because the height of this plant is less than 50 cm, and the ground coverage proportion is low.

SDI has a negative effect on ESA, based on the predicted marginal effects. The optimum condition for the Eurasian skylark occurs when the landscape is homogeneous (one of the land uses is dominant, which supports the Eurasian skylark abundance around the birds' nests).

4.5. Conclusions

We analyzed the relationships among the abundance data of Eurasian skylark and the land-cover/land-use type, and land-cover/land-use heterogeneity in a selected study area (Schleswig-Holstein). Based on the GLM model averaging, in Schleswig-Holstein, pastures and shrub and/or herbaceous vegetation associations provided suitable habitats for the Eurasian skylark. Among the land-use types inside the agricultural areas, pasture, wheat, and potato were found to be suitable habitat types for this bird. Land cover and crop heterogeneity had negative impacts on the population of the Eurasian skylark. We identified crop types, which had positive (potato and sugar beet) or negative (silage maize, permanent crops, and rape) effects on the abundance of this bird species. Furthermore, we ranked the variables based on their importance in the GLM models. We can state that introduction of energy crops (silage maize), and the homogenization process of energy landscape have a negative effect on the population of the Eurasian skylark in the entire study area.

5. Modelling the Impacts of Habitat Changes on the Population Density of Eurasian Skylark (Alauda arvensis) Based on Its Landscape Preferences

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Abstract

The dramatic decline of the abundance of farmland bird species can be related to the level of land-use intensity or the land-cover heterogeneity of rural landscapes. Our study area in central Europe (Hungary) included 3049 skylark observation points and their 600 m buffer zones. We used a very detailed map (20 × 20 m minimum mapping unit), the Hungarian Ecosystem Basemap, as a land-cover dataset for the calculation of three landscape indices: mean patch size (MPS), mean fractal dimension (MFRACT), and Shannon diversity index (SDI) to describe the landscape structure of the study areas. Generalized linear models were used to analyze the effect of land-cover types and landscape patterns on the abundance of the Eurasian skylark (Alauda arvensis). According to our findings, the proportions of arable land, open sand steppes, closed grassland patches, and shape complexity and size characteristics of these land cover patches have a positive effect on skylark abundance, while the SDI was negatively associated with the skylark population. On the basis of the used statistical model, the abundance density (individuals/km^2) of skylarks could be estimated with 37.77% absolute percentage error and 2.12 mean absolute error. We predicted the skylark population density inside the Natura 2000 Special Protected Area of Hungary which is 0-6 individuals/km^2 and 23746±8968 skylarks. The results can be implemented for the landscape management of rural landscapes, and the method used are adaptable for the density estimation of other farmland bird species in rural landscapes. According to our findings, inside the protected areas should increase the proportion, the average size and shape complexity of arable land, salt steppes and meadows, and closed grassland land cover patches.

Keywords: Land cover; Land use; Landscape structure; Eurasian skylark; Farmland bird; Prediction; Natura 2000;

5.1. Introduction

In the terrestrial ecosystems of the world, the dominant land-cover category is agriculture (38%), including the arable-land use type (Fao, 2014). In Europe, this value is much higher, at 45% (EBCC, 2020). The agricultural land-cover category contains various land-use types with different levels of human impact. The heterogeneity and spatial structure of these land-use/land-cover (LULC) patches vary greatly across rural areas, which has strong impact on farmland-bird diversity in Europe (Morelli, 2013; Toth et al., 2020). Many articles have determined that the decreasing trend of farmland birds is strongly connected with the intensity of agricultural management (level of use of fertilizers etc.) (Gottschalk et al., 2010; Guerrero et al., 2012; Moreira et al., 2005; Verhulst et al., 2004). Very few studies have investigated the dramatic decline of the abundance of farmland birds, and its connection with change in landscape structure and land-cover heterogeneity (Gil-Tena et al., 2015; Moreira et al., 2005; Piha et al., 2003). There are some regional (country)-scale studies that analyse the connection between land-cover types and farmland-bird population data (Borges et al., 2017; Csikós and Szilassi, 2020; Link and Schleupner, 2007; Moser et al., 2002; Schindler et al., 2013; Peter Szilassi et al., 2019). These studies have indicated that the abundance of farmland birds is significantly connected with the intensity of agricultural cultivation, crop heterogeneity, and land-use change. Most articles focus on small, local study areas and analysing the connection between Eurasian skylark (Alauda arvensis) abundance, and the proportions of crop type, height, coverage and heterogeneity (Berg et al., 2015; Gottschalk et al., 2010; Guerrero et al., 2012; Hoffmann et al., 2018; Praus and Weidinger, 2015; Redlich et al., 2018; Peter Szilassi et al., 2019). The skylark does not prefer the fragmented landscapes by urbanized area, road network, hedgerows and heterogeneous land cultivation areas (Loretto et al., 2019; Moreira et al., 2005). The agriculture is the dominant land use (matrix) of the European NATURA 2000 network, where the size and shape characteristics of different LULC patches, and the land cover heterogeneity can be essential for the protection of farm-land bird species. Therefore, we hope that our results can be adding some new suggestions for the landscape planning and habitat design of national parks, NATURA 2000, and other protected areas. Our research also can provide important component for achieving the goals of the EU Birds directive (European Commission, 2021).

The skylark is one of the most common farmland bird of rural landscapes in Eurasia, including Hungary. In the European Union, the Eurasian skylark has a declining trend in population between 2000 and 2018: Norway -47%, Lithuania -41%, France -38%, Czech Republic -29%, Hungary -24% and Germany -17%. Most individuals that breed in Central Europe spend the winter in the Mediterranean region, but small groups can stay in Hungary for winter (Csörgo et al., 2009). This bird species has been introduced in-to the Nearctic, Australia and New Zealand (Campbell et al., 2020; Cramp, 1988). From large-scale studies, habitat preferences, including for crop structure and heterogeneity are well-known. On the basis of small-scale regional-level studies, the regional-scale habitats and land-cover heterogeneity preference of a given species can be understood (Peter Szilassi et al., 2019). However, the connection between the spatial pattern of LULC patches (described with landscape indices), and skylark abundance is not clear.

In this study, we describe the landscape structure of rural landscapes with a very detailed (20 X 20m minimal mapping unit) LULC map, the Hungarian Ecosystem Basemap (HEB). Comparing skylark abundance data with the HEB, we could identify preferred and nonpreferred skylark habitats, and calculate their landscape indices. The preferred habitat was separated into arable lands and grasslands because we wanted to analyse the effect of arable land and grassland landscape metrics on the skylark population. According to the pattern and process paradigm, which analyse the relationship between the landscape patterns spatial distribution and landscape processes, landscape indices are widely used as indicators of biodiversity and habitat changes (Borges et al., 2017; Campbell et al., 2020; Szilassi et al., 2017; Uuemaa et al., 2013, 2009; Walz, 2011). After we identified preferred and non-preferred habitats for skylarks, we could calculate shape- and size-related class-level landscape metrics, and land-cover heterogeneity, and estimate the collective impact of these variables on skylark abundance (Borges et al., 2017; Csikós and Szilassi, 2020; Gil-Tena et al., 2015; Schlager et al., 2020; Peter Szilassi et al., 2019; Vögeli et al., 2010).

The main goals of this study were to:

- identify skylark land-cover preferences on the basis of the local-scale LULC map;
- analyse the impact of landscape patterns of preferred and nonpreferred land-cover classes (habitats), and estimate the impact of all LULC-related variables (proportions, shape, and size characteristics of patches, heterogeneity) on skylark abundance; and
- estimate, based on our findings, the skylark population density inside the Natura 2000 Special Protection Area (SPA) of Hungary based on the HEB land cover categories.

According to our hypotheses the population density of skylark is predictable based on the preferred LULC categories of skylark and landscape indices (proportion of LULC categories and shape and size related landscape metrics). The methodology is adaptable for analysing the impact of landscape composition on other farmland-bird populations, and for predicting the population density of the skylark, in protected areas, where field observation-based datasets are not available.

5.2. Materials and Methods

5.2.1. Study Area

Hungary is located in the Carpathian basin (45°43’ to 48°35’N and 16°06’ to 22°53’E) in central Europe, and is part of the Pannonian biogeographical region (Figure 5.1). The total area is 93,033 km^2, and its elevation ranges from 77 to 1014 m a.s.l. The most important land-cover type (61%) is agricultural land (Farkas and Lennert, 2015). A further 20.7% is natural and semi-natural grasslands and forest, and 5.5% is built-up area. In the 1990s, a dramatic landscape change was mainly caused by land privatization. Agricultural land with low quality and poor agroecological conditions were abandoned (Tryjanowski et al., 2011). The common agricultural policy of the EU (strong decline of grazing livestock) and land abandonment caused the transformation of arable lands into non-cultivated lands, and the fast and spontaneous reforestation of open grasslands (Báldi and Faragó, 2007).

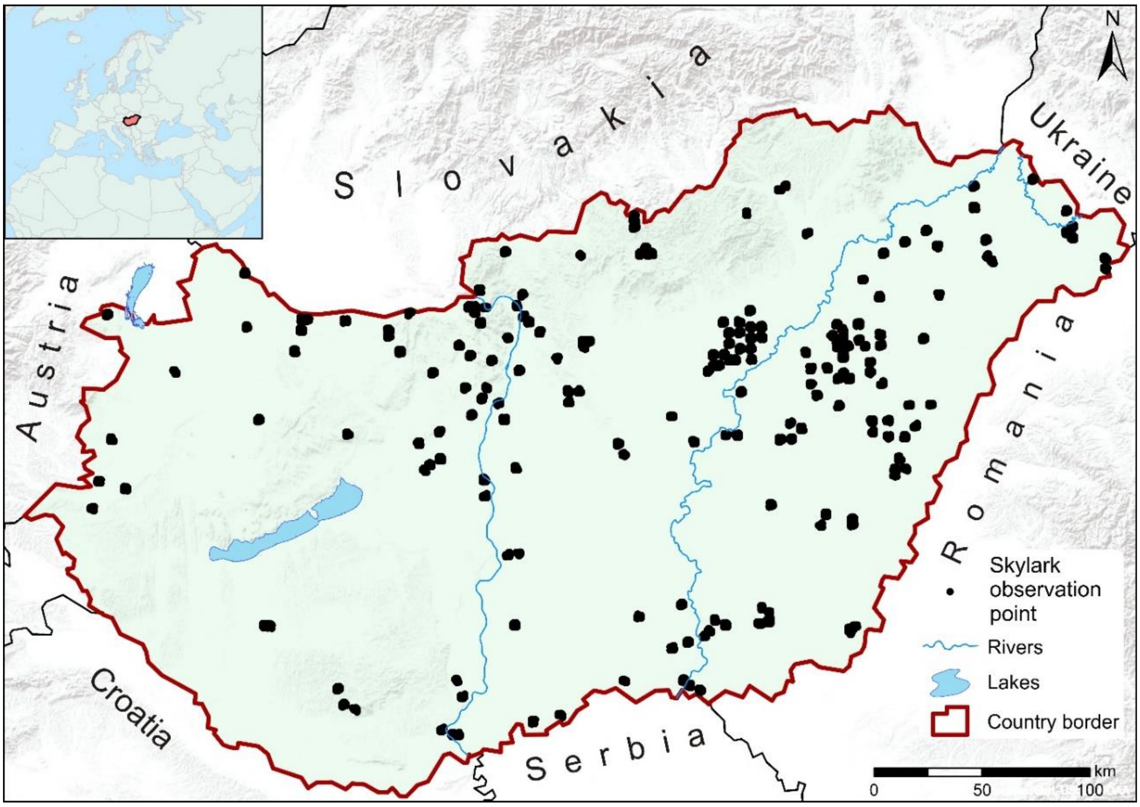

Figure 5.1. The spatial distribution of the MMM survey observation points in Hungary, where the Skylark occurred in 2015 (3049 observation points)

5.2.2. Databases

Skylark-Abundance Data

In Hungary, a countrywide bird-monitoring survey has been conducted every year (like in 2015) by approximately 800 field surveyors who add their field-observation datasets into the Hungarian Common Bird Monitoring Database (MMM) (Szép et al., 2012; Szép and Gibbson, 2000; Szép and Nagy, 2001). The volunteers were not randomly distributed across Hungary. The survey allowed that the observers choose their area of observation. Each observation point received two spring visits, and the abundance of birds was observed (by hearing and visually) within a 100-meter radius of each point. There is a minimum 500 m distance between the observation points. The surveyors left a minimum of two weeks be-tween visits in mid-April and mid-June. The count was accomplished between 5:00 and 10:00, when wind speed was less than 5 m/s and there was no rain. Each observation point contains the average number of observed birds which were counted at the point in the two spring visits (Szép and Gibbson, 2000; Szép and Nagy, 2001). In 2015, surveyors counted 6763 skylark individuals across 3049 field observation points (mean value: 2.22, maximum: 34, standard deviation: 4.38.). We used MMM survey points from 2015 in the study area because the HUB land-cover map was also available from that time scale. We analysed the proportion and spatial configuration of the landscape in the 600m radius surrounding of the MMM observation points. 600 m buffer zone was chosen, because many author found that landscape composition and land cover types have the highest impact on the abundance of this species within this radius (Engel et al., 2012; Peter Szilassi et al., 2019). Land use types also have an effect on abundance of skylark population within 600m buffer radius (Miguet et al., 2013). We used a very detailed (20 X 20 m mapping units) country scale LULC HEB maps (Agrárminisztérium, 2019) for analyses of the LULC characteristics inside these buffer zones. Unfortunately, the more detailed country scale statistical datasets about the crop structure surroundings of the observation points were not available. Most of the MMM observation points (43%) is situated inside the NATURA 2000 SPA Protected areas, where the grasslands are mowed one-time every year after 15th of June.

Land-Cover Database—Hungarian Ecosystem Basemap

The digital LULC HEB was created by the Hungarian Ministry of Agriculture. The basis year of this database is 2015. This very high resolution LULC dataset was based on other LULC maps of the European Copernicus Program, such as Urban Atlas, Corine Land Cover and High-Resolution Layers, and Sentinel-2 images. The dataset has a 20 × 20 m resolution (minimal mapping unit) and three Levels of categories. Six classes in Level 1, 22 classes in Level 2, and 56 classes in Level 3 (see Appendix 5.1). The database also contained three additional LULC categories in Level 4. We used the second level for analysis, and regrouped the LULC classes to reduce the number and the likelihood of autocorrelation between them. Our dataset for statistical analyses contained the following main LULC categories inside the buffer zones (code and proportion from the total area):

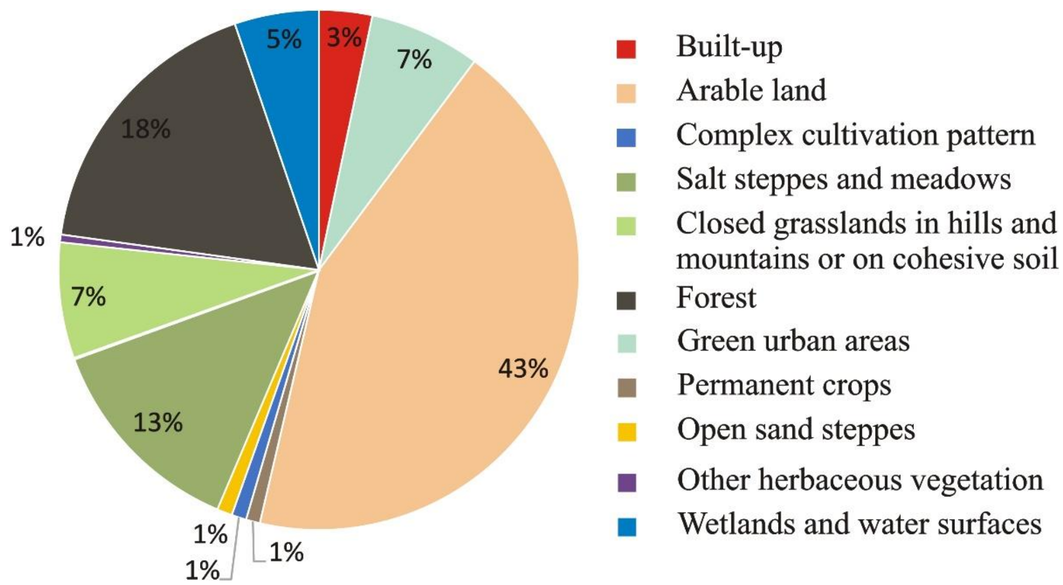

Figure 5.2. Proportion of the main land cover categories in the 600-meter buffer zones, where the Skylark abundance were detected (3049 observation points) based on Hungarian Ecosystem Basemap

In our investigations, we aggregated the LULC categories of the HEB database, such as "forest", "wetlands and water surfaces" LULC categories (Appendix 5.1). The HEB web map and its documentation are freely available (downloadable) on this website: http://alapterkep.termeszetem.hu/ (Agrárminisztérium, 2019). 46% of the country is arable land

and cereals take the 62% of the arable lands. According to the country scale statistical datasets, the proportion of the crop structure in Hungary is 23% wheat, 26% grain maize, 14% sun-flower, 7% barley, 5% rape and 7% fodder crops inside the arable lands (Hungarian Central Statistical Office, 2020).

5.2.3. Landscape Metrics

The HEB database was applied to calculate size- and shape-related landscape metric parameters. Patch-level landscape indices were calculated for each LULC patch of the HEB database with the V-LATE 2 extension of Arc GIS 10.3 software (Lang and Tiede, 2003). Patch level metrics, created for individual land cover patches, characterize the spatial character and context of patches. These patch metrics serve primarily as the computational basis for developing a landscape metric. During our landscape metrics analyses, we calculated the following patch-level landscape metrics, which represent size and shape characteristics of land-cover patches. The mean patch size (MPS) has been widely applied in landscape ecology, since it is commonly agreed that the occurrence and abundance of different species and species richness strongly correlates with the mean patch size. The shape complexity of individual LULC types was quantified by using landscape metrics (MFRACT). We applied the Shannon Diversity Index (SDI) to determine the landscape heterogeneity (Uuemaa et al., 2009). We calculated these landscape indices (MPS, MFRACT, SDI) inside the 600m radius buffer zones.

Table 5.1. Descriptions and calculations of the applied landscape indices (Blaschke, 2006; Forman, 1995; Uuemaa et al., 2013)

Structural feature	Index	Name and description	Calculation
Size and shape related metrics	MPS	Mean patch size is computed by dividing the area of the patches of the total landscape (or class) by the number of patches.	$MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}$ where a_{ij} represents the area of the j^{th} patch in the i^{th} class, n_i represents the number of patches in the i^{th} class, n represents the number of patches (> 0).
	MFRACT	Mean fractal dimension index equals 2 times the logarithm of the patch perimeter (m) divided by the logarithm of patch area (m^2).	$MFRACT = \frac{\sum_{j=1}^{n} \left(\frac{2\ln p_{ij}}{\ln a_{ij}}\right)}{n_i}$ where p_{ij} represents the perimeter of the j^{th} patch in class i^{th}, a_{ij} represents the area of the j^{th} patch in class i^{th}, n_i represents the number of patches in the i^{th} class, n represents the number of patches (1-2).
Landscape Heterogen eity	SDI	The Shannon diversity index (SDI) provides more information about area composition than simply area richness (i.e., the number of land-cover types present).	$SDI = -\sum_{i}^{m}(P_i * \ln(P_i))$ where (m) represents the number of different land-cover types, P_i = the relative abundance of different land-cover types in each BMMU quadrant or LUCAS transect.

5.2.4. Statistical Analyses

To understand the relationship between LULC types and skylark abundance, first we had to identify those LULC categories which are selected (used as habitat) by skylark or are avoided. We applied a preliminary test to identify the group of correlated land-cover and landscape index variables using variance inflation factors (VIFs), and the explanatory variables were not linearly related. VIF values were between 0 and 1.9, which shows that the multicollinearity is low between the variables (LULC types and indices). The arable-land category was ignored from statistical analyses (model) be-cause in Hungary and other European countries, the agricultural land is the matrix (dominant LULC type) in the landscape, so the proportion of this category shows strong autocorrelations with other LULC types. We used generalized linear models (GLM) to determine the impact of land cover and landscape structure (composition) on skylark abundance. We applied negative binomial models (link=log) to account the overdispersion of skylark-abundance data (tested by overdispersiontest function of AER package in R). Models with all possible combinations of explanatory variables were generated, and we established Akaike's information criterion to rank them with the "dredge" function from the MuMin package in R (Barton, 2015). We used model averaging for competitive models (delta AICc<2) to include uncertainty arising from the high number of candidate models (Appendix 5.3) (Burnham and Anderson, 2002). The significance of the variables was estimated by the LmerTest package (Kuznetsova et al., 2020). We constructed two groups from the LULC categories of the HEB database based on GLM results, namely, preferred (significant positive relation) and nonpreferred (significant negative relation) land-cover types. We analysed the relationship between the landscape metrics of the preferred (as habi-tats) and nonpreferred land-cover types, and the skylark abundance data with negative binominal GLM and model averaging. In the next step in our investigation, we analysed the shape and size characteristics of those LULC types which showed significant positive relation with skylark abundance. These land-cover types were separated into arable lands and grasslands because we wanted to analyse the effect of arable land and grassland landscape metrics on the skylark population. In this model, the ar-able land category has been used. The distribution of landscape metric variables was not normal, so logarithmic transformation was used to normalize the data. These variables were in different dimensions, so we created a range function in R that trans-formed the variable values into a number between 0 and 1:

$$Range\ function = \frac{x - \min(x, na.rm = T)}{\max(x, na.rm = T) - \min(x, na.rm = T)}$$

where Range function is a number that describes the given number between 0 and 1, na.rm = T means that NA values were removed, min is the minimal value of the list, and max is the maximal value of the list.

On the basis of the output of the statistical model, we could describe the optimal landscape configurations for this species.

5.2.5. Model Validation

We calculated the predicted marginal effects (ggeffects package in R) of the preferred land-cover types and their landscape metrics on the skylark population (Lüdecke, 2018). To validate our model, we set up a training and a testing group (66.6% and 33.3% proportion, respectively) with random sampling (sample.split function from caTools 1.17 package) on the basis of our dataset in R statistics software. We used the predict function from the car package to calculate the estimated skylark-abundance data. Model accuracy was measured by three indices: Spearman's rank correlation to show the relationship between observed and predicted values, mean absolute error to show the distance of the predicted values from the observed values (Willmott and Matsuura, 2005), and mean absolute percentage error to show the percentage of error between observed and predicted values (De Myttenaere et al., 2016).

5.2.6. Prediction of Skylark Population in Natura 2000 SPAs

We could estimate skylark population density using the 600 m buffer areas and the HEB dataset. The centres of the buffer zones were in a regular grid (1200 × 1200 m) in-side the Natura 2000 SPA dataset. We used the Natura 2000 SPA areas as the basis of our prediction site, because of the Eurasian skylark is a very common indicator species of agrarian landscapes

(Natura 2000 Annex I. list). In Hungary the Natura 2000 SPA areas are typical agrarian landscapes which contain Urban areas (1.5%), Croplands (31.7%), Grasslands and other herbaceous vegetation (21.7%), Forest and woodlands (27.8%) and wetland and water surfaces (17.2%). Mowing of the grasslands inside the Natura 2000 sites is regulated by the law. The mowing machine should cut the grass 10 cm above the soil surface. Mowing should not begin before 1 of July, to protect the ground nesting birds. The number of the animals and the method (it is different based on the grassland type) are also regulated by the law. Prediction was performed based on the model results that analyzed the connection between the preferred area and the landscape metrics. Landscape indices were calculated inside the Natura 2000 SPAs. The estimated skylark population was calculated by the predict function in R software. Figure 5.3 shows the spatial distribution of the 600 m buffer zones.

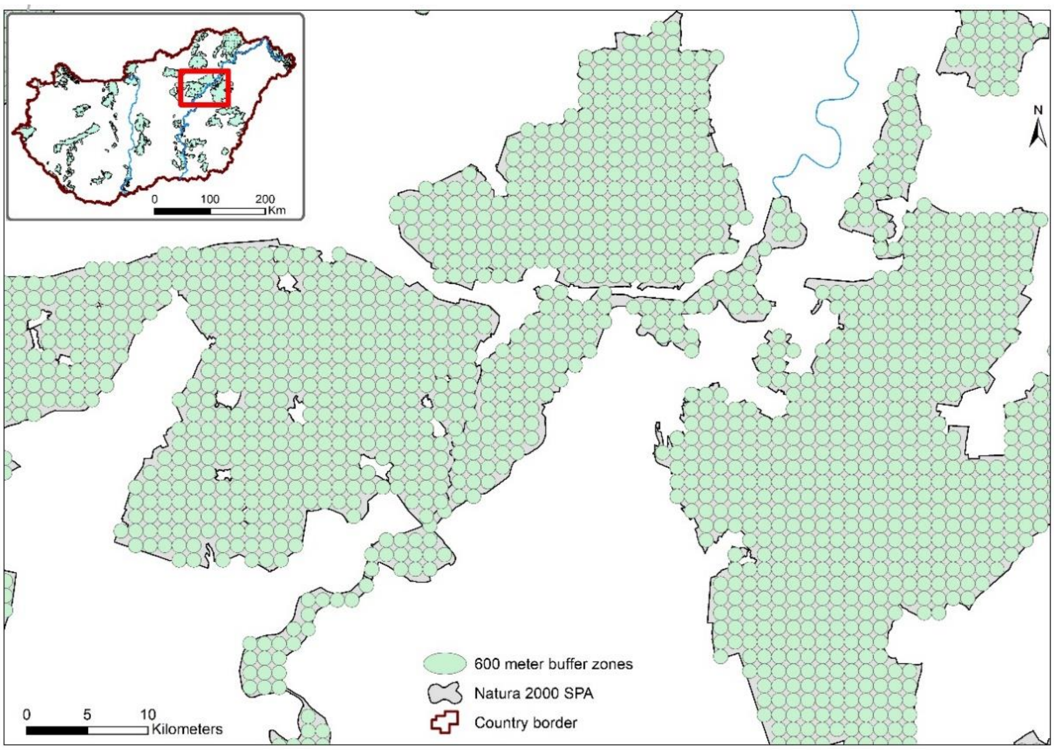

Figure 5.3. Example the spatial distribution of the 600-meter buffer zones inside a Natura 200 Spa protected area of Hungary.

5.3. Results

5.3.1. Relationship between Land-Cover Proportions and Skylark Abundance

Based on GLM results, we identified two main groups (classes) of the LULC categories of the HEB database. Preferred LULC categories that were considered the habitats of the Eurasian skylark because they showed significant positive relation with skylark abundance were those such as salt steppes and meadows, and closed grasslands in hills and mountains. The closed-grasslands LULC category showed the highest significant relation, thereby having the most important effect on skylark abundance. The arable-land LULC category is also a preferred category according to the literature (Chamberlain et al., 1999; Csikós and Szilassi, 2020; Praus and Weidinger, 2015; Schlager et al., 2020). The nonpreferred group (class) of LULC categories contains land-cover types with significant negative relations with skylark abundance: built-up land, green urban areas, complex cultivation patterns, forests, and wetlands and water surfaces. The complex-cultivation-pattern LULC category had the strongest negative association with the skylark population, followed by wetland and water surfaces, and green urban areas. The relative importance of the significant variables was 100% in all cases (Table 5.2).

Table 5.2. Summary table for LULC categories, which shows the GLM results after multimodel averaging of best candidate models showing relative importance of each explanatory variable on Skylark abundance, estimated parameter values ± Standard deviation. (For detailed descriptions of the LULC categories see Appendix 5.1).

Variable	Estimates	Standard deviation	Conf. Int (95%)	P-Value	Relative importance (%)	*VIF*
Built-up	-0.019 *	0.008	-0.035 – -0.003	0.022	100	1.88
Green urban areas	-0.024 ***	0.005	-0.034 – -0.014	<0.001	100	1.93
Permanent crops	-0.014	0.013	-0.040 – 0.013	0.308	24	1.03
Complex cultivation pattern	-0.034 *	0.015	-0.064 – -0.005	0.021	100	1.05
Open sand steppes	-0.014	0.012	-0.037 – 0.009	0.228	19	1.02
Salt steppes and meadows	0.059 ***	0.002	0.054 – 0.063	<0.001	100	1.17
Open rocky grasslands	-0.045	0.114	-0.269 – 0.180	0.697	100	1.06
Closed grasslands in hills and mountains or on cohesive soil	0.067 ***	0.004	0.058 – 0.076	<0.001	100	1.03
Other herbaceous vegetation	-0.019	0.075	-0.165 – 0.128	0.805	80	1.07
Forests	-0.021 ***	0.002	-0.025 – -0.016	<0.001	100	1.11
Wetlands and water surfaces	-0.030 ***	0.006	-0.041 – -0.018	<0.001	100	1.02
Number of MMM observations (data pairs): 3049						
			* p<0.05 ** p<0.01 *** p<0.001			

Positive significant relation with skylark abundance
Negative significant relation with skylark abundance
No significant relation with skylark abundance

5.3.2. Relationship between Landscape Structure (Compositon) and Skylark Abundance

The landscape metrics that describe the shape and size characteristics of the preferred and nonpreferred LULC classes showed different directions of significant relation with skylark abundance (Table 5.3). The metrics that describe the shape complexity and size of the LULC patches of preferred LULC categories of the HEB database showed significant positive relations with skylark abundance. The shape complexity (MFRACT index) of the preferred LULC patches has stronger influence on the skylark abundance than the mean patch size (MPS). The shape complexity and size of the nonpreferred LULC categories had significant negative relation with skylark abundance in this case, MPS had higher association with skylark abundance. (Table 5.3). Land-cover heterogeneity, described with SDI, had a significant negative effect on skylark abundance, which showed that this species prefers a homogeneous landscape.

Table 5.3. Summary table for landscape metrics, which shows the GLM results after multimodel averaging of best candidate models showing relative importance of each explanatory variable on Skylark abundance, estimated parameter values ± Standard deviation.

Variable		Estimates	Standard deviation	Conf. Int (95%)	P-Value
Shape and size related landscape metrics	MPS of preferred LC types	0.4345 ***	0.0001	0.2324 – 0.6156	<0.001
	MFRACT of preferred LC types	1.1635 ***	0.3349	0.5072 – 1.8199	0.001
	MPS of non-preferred LC types	-1.9126 ***	0.0004	-2.7145 – -1.1237	<0.001
	MFRACT of non-preferred LC types	-1.1993 **	0.4205	-2.0236 – -0.3751	0.004
Landscape heterogeneity	Shannon Diversity Index of landscape	-1.3711 ***	0.1639	-1.6923 – -1.0500	**<0.001**
Number of MMM observations (data pairs): 3049					

* p<0.05 ** p<0.01 *** p<0.001

5.3.3. Impact of Preferred Land-Cover Categories and Their Landscape Metrics

Total grassland proportion had the highest association with skylark abundance, as shown in Table 5.2; the average size of arable-land patches (MPS) was more important from an abundance point view of this species than the mean patch size (MPS) of grassland patches. The complexity of grassland patches (MFRACT) had a significant positive association with skylark abundance, while the shape characteristics of arable land had no significant relationship with skylark abundance. The predicted margin-al-effect graphs visualize the above-described connections between proportions of LULC categories, size- and shape-related landscape indices, and the estimated population density changes of the skylarks (Figure 5.4). According to the modelled population density changes, in the case of 100% grassland coverage of a hypothetical landscape, we could find about 4–6 skylark individuals/km^2. While the connection between the change in proportions of different land-cover types showed a near exponential curve, landscape metrics showed almost flat linear connections with estimated skylark abundance.

On the basis of our results (Appendix 5.2), we could create an equation that describes and estimates the skylark population in a given landscape.

$$Skylark_{population} = -3.24 + 1.29 * MPS_{arable\ land} + 0.97 * MPS_{grassland} + 0.63 * MFRACT_{grassland} + 1.65 * Area_{arable\ land} + 2.4 * Area_{grassland}$$

where $Skylark_{population}$ is the skylark number density (individual/km^2), $MPS_{arable\ land}$ is the mean patch size of arable land, $MPS_{grassland}$ is the mean patch size of grasslands, $MFRACT_{grassland}$ is the mean fractal dimension of grasslands, $Area_{arable\ land}$ is the proportion of arable land, and $Area_{grassland}$ is the proportion of grasslands.

5.3.4. Model Validation

According the validation of our results, there was significant Spearman's correlation between the observed and predicted values of skylark abundance. Mean absolute error shows the distance between the predicted and observed abundance values of this species, which is +–2.12. Mean absolute percentage error (MAPE) shows the prediction accuracy of the model in percentage; in this case, it was 37.77%. The accuracy of this model based on the MAPE was 62.23% (Table 5.4). If the model contains just the land cover types, the MEA is 2.95; MAPE is 46.56% and the Spearman correlation coefficient is 0.493.

Table 5.4. Summary table of the correlation and error indices, which show the accuracy of the predicted values, based on land cover types and land cover types + landscape indices

	Spearman's Rho	**Mean absolute error**	**Mean absolute percentage error**	**Number of data pairs**
Land cover types + landscape metrics	0.504**	2.12	37.77%	949
Land cover types	0.493**	2.95	46.56%	
	** *p<0.01*			

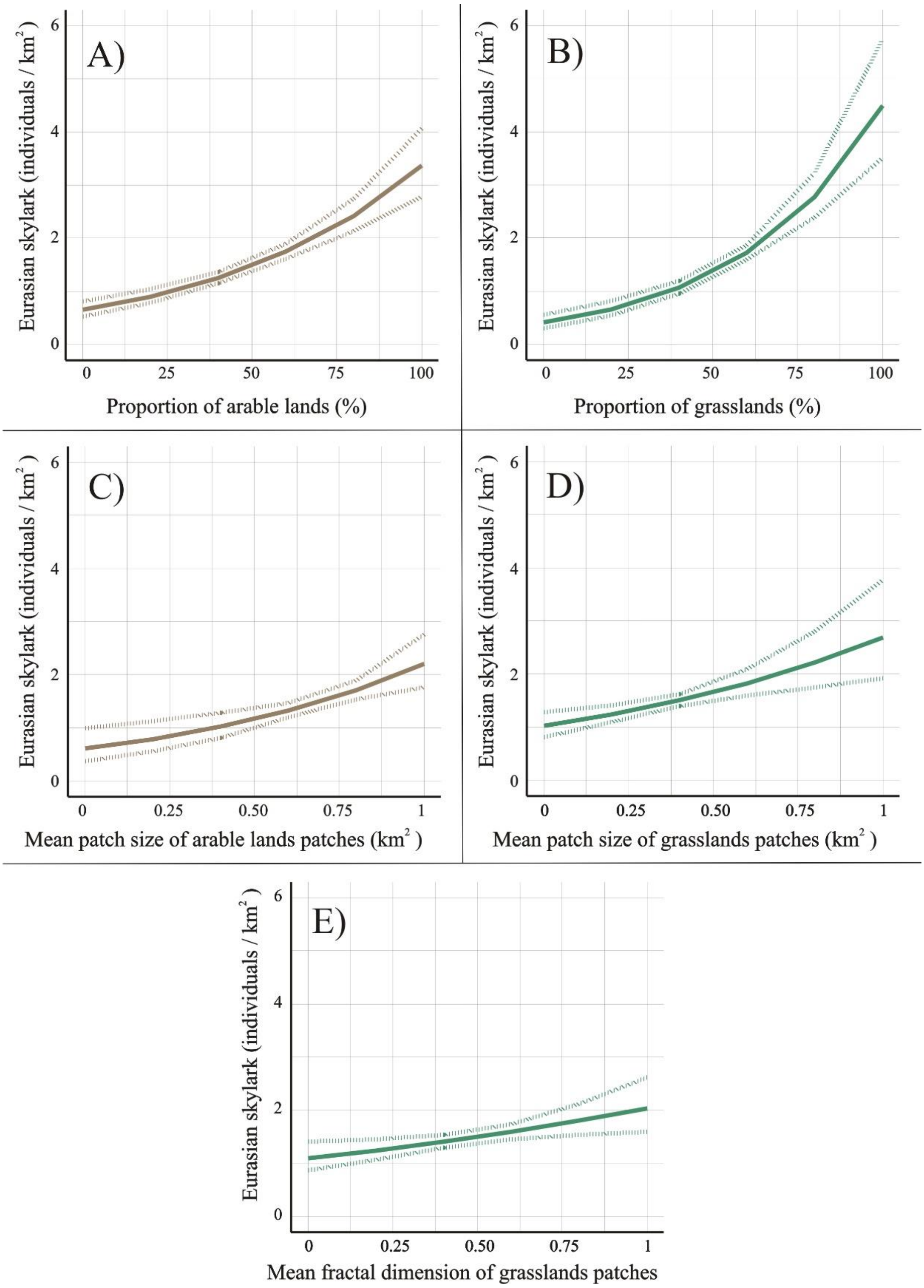

Figure 5.4. Predicted marginal effects between the skylark individuals / km^2 proportions and land-scape metrics of arable and grasslands. The confidence intervals (95%) of the prediction are shown between the dotted lines. (A, Connection between the proportion of arable land and estimated population density of skylark, B, Connection between the proportion of grassland and estimated population density of skylark, C, Connection between the MPS of arable land and estimated population density of skylark, D, Connection between the MPS of grassland and estimated population density of skylark, E Connection between the MFRACT of grassland and estimated population density of skylark)

5.3.5. Prediction of Skylark Population of Natura 2000 Special Protection Areas of Hungary

The spatial distribution of the predicted skylark population in each 600-meter zone of the Natura 2000 SPAs of Hungary was very diverse (Figure 5.5). The total investigated Natura 2000 SPA was 13,514 km^2, which cover the most valuable agroecosystems and rural landscapes of Hungary. Based on model prediction (predict function in R) inside these protected areas, approximately 23,746 skylark individuals were predicted. The density of this species is the highest in the agricultural-landscape-dominated areas of the great Hungarian plain.

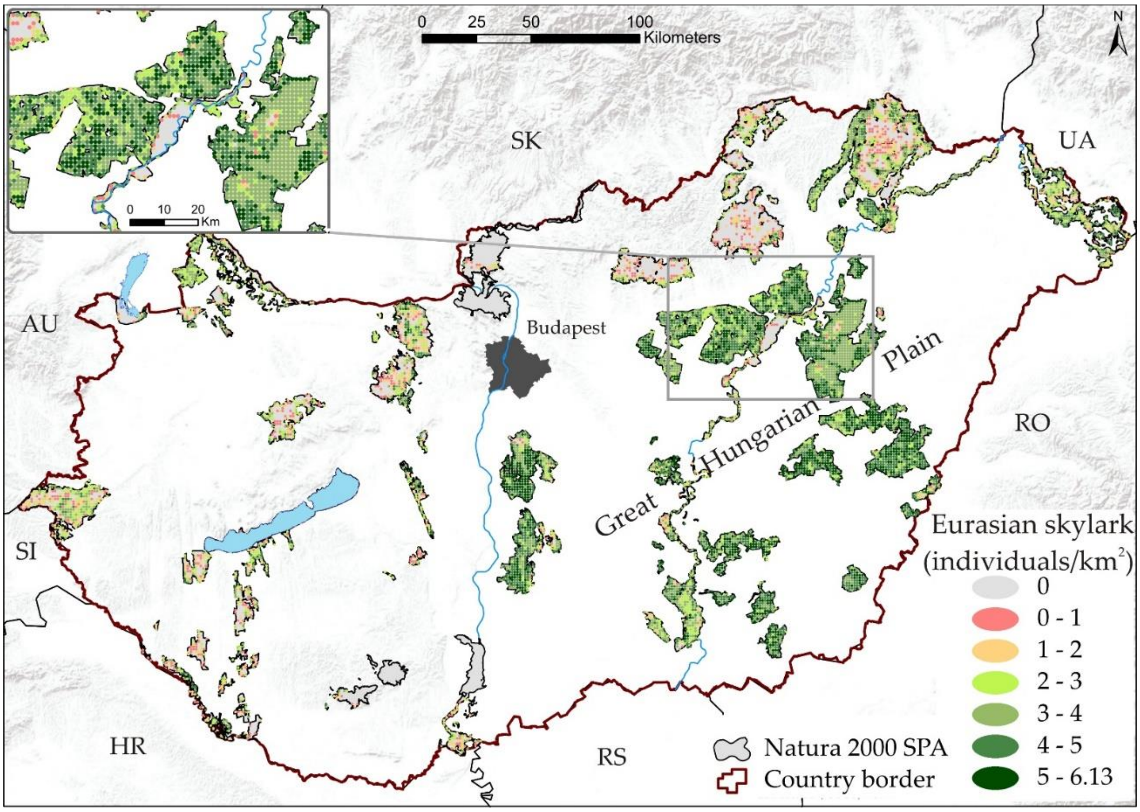

Figure 5.5 Predicted Eurasian skylark population (individuals/km2) in the 600 m buffer zones inside the Natura 2000 SPA area

5.4. Discussion

There are several publications analysing the relationship between skylark and LULC (Gevers et al., 2011; Guerrero et al., 2012; Nagy et al., 2009; Perkins et al., 2000; Wretenberg et al., 2007) in local small study areas, but our very detailed LULC dataset (HEB) offers a unique opportunity to obtain regional (country)-scale information about this relationship. In our study, we considered both datasets describing proportions of LULC categories and landscape indices that describe the shape and size characteristics of preferred (habitat) and nonpreferred LULC categories. Based on our research findings, population density (individuals/km^2) could be estimated because there was a significant statistical relationship between proportions, the shape and size characteristics of different LULC types, and the abundance of this farmland bird. One new finding from our research is that, for the estimation of skylark population density, it is necessary to consider landscape indices together with the proportions of different LULC categories because shape (mean fractal dimension) and size (mean shape size) characteristics of these LULC categories also have significant association with skylark abundance. Based on our finding we have predicted the number skylarks inside the Natura 2000 SPA areas in Hungary.

5.4.1. Impact of proportions of LULC categories on skylark abundance

We could select two LULC groups (classes) from the land-cover types of a very detailed (20 × 20 m resolution) LULC map. Nonpreferred types had negative significant relation with skylark abundance. These were built-up and green urban areas, which negatively affected the population because of the lack of openness and the high proportion of constructed surfaces. Our findings are confirmed by other international publications (Gottschalk et al., 2010; Guerrero et al., 2012; Peter Szilassi et al., 2019). The complex cultivation pattern land-cover type has negative significant relation with skylark data. Other authors underlines that the skylarks do not prefer heterogeneous agricultural lands because this rural landscape contains many different LULC patches, including also those that are not preferable to the skylark, like vineyards, fruit and berry plantations (because of its height, they obscure the view) (Berg et al., 2015; Csikós and Szilassi, 2020; Redlich et al., 2018; Peter Szilassi et al., 2019). Small parcels of, annual crops, city gardens pastures, fallow lands and/or permanent crops somewhere with scattered houses. Forest and wetland LULC categories are well-known nonpreferred land-cover types of the skylark. The skylark is a typical farmland bird; therefore, it is not a surprise that wetland areas, water bodies, and water courses are not suitable habitat types for this species. The main reason of the negative significant relation of the forest is the lack of openness, which is very important for the skylark (Berg et al., 2015; Csikós and Szilassi, 2020; Sauerbrei et al., 2014; Peter Szilassi et al., 2019). In our research we were not take difference be-tween the type of forests, because according to previous studies all types of forest areas are not habitats of this species.

In the estimation of skylark population density, the preferred land-cover types had higher weights (were more important) than those of the nonpreferred LULC categories. Arable land is a well-known habitat type of this farmland bird species according to the international literature (Csikós and Szilassi, 2020; Dietzen et al., 2014; Hoffmann et al., 2018, 2016; Praus and Weidinger, 2015). Unfortunately, in Hungary is no available detailed country scale spatial statistical data about the cultivated crop types inside the arable lands (cropland) areas. According to the available most detailed Hungarian LULC dataset, the HEB dataset the 57% of Hungary is covered by agricultural fields and its 81% is arable land (Cropland). Grassland and pasture areas are also preferred LULC categories for skylark, (Csikós, 2020; Hamer et al., 2006; Koleček et al., 2015; Moreira et al., 2005; Piha et al., 2003; Reif and Hanzelka, 2016; Peter Szilassi et al., 2019). The HEB dataset allow us to analyse the impact of different types of grassland on skylark abundance. We did not find significant statistical relations with open sand steppes and open rocky grasslands because the number of 600 m circle radius observation points of LULC categories have been low, and these landscape conditions (too-fragmented grassland areas with very short and very sparse vegetation) are not suitable for breeding skylarks (Báldi et al., 2005; Dietzen et al., 2014). There was a significant positive relation between skylark abundance, and the LULC categories of salt steppes and meadows, and closed grasslands. Each LULC category is suitable for nesting breeding skylarks because of the medium vegetation height and optimal proportion inside the 600 m radius circles. Our results are similar with those of others, who described strong relationship between closed grasslands and meadows and sky-lark abundance, the reason of this relation could be the larger amount of food (Brotons et al., 2005; Donald et al., 2001; Suárez et al., 2003; Wolff et al., 2001). According to our findings for the prevention of the farmland bird habitats, the EU agri-environmental policy should pay more attention to the management of salt steppes and meadows, and closed grasslands. To increase the population density of skylark, the mean patch size and the proportion of these land cover types (compare to all) in the landscape should increase. In case of the protected grassland areas, one of the biggest ecological problems is the spontaneous spreading of the bush vegetation, which can reduce the skylark habitats. If we want to stop this process, and keep the openness of the landscapes, we should reduce the size and the shape of the bush and forest patches inside these grassland areas. Therefore, we must eradicate the spontaneously spread bush vegetation (which often full of invasive species) by the proper way of grazing or haymaking, the grasslands can keep its size, shape, and openness characteristics in the protected landscapes. This kind of management of protected areas can preserve not only the vegetation diversity of grasslands but it has also important key factor in the skylark habitat protection.

5.4.2. Impact of Land-Cover Categories and Their Landscape Metrics

The landscape metrics of the preferred LULC classes showed positive significant relation with skylark abundance, meaning that, if arable-land and grassland proportion and shape complexity was higher, then the skylark population would also be higher. The landscape metrics of the nonpreferred LULC classes showed negative significant relation with the skylark population, meaning that, in landscapes with small size and in compact-shape nonpreferred LULC categories, skylark population density (abundance) would be higher.

LULC landscape heterogeneity has a negative effect on the skylark in this scale, where one land cover patch can contain more parcels. If landscape heterogeneity in-creases, the skylark population declines. This species prefers the homogenous LULC structures, which is in accordance with the results of other authors (Báldi et al., 2005; Berg et al., 2015; Csikós and Szilassi, 2020; Redlich et al., 2018; Peter Szilassi et al., 2019).

The grassland proportion had the highest association with the skylark population. This species usually nests and feeds in grasslands. The proportion of arable land has a high association with skylark abundance, but the level of its significance is lower. In the case of the MPS, the opposite phenomenon was observed: the MPS of arable lands (arable land patches of HEB) had a higher effect on skylark abundance than that of grassland. The skylark does not prefer small size arable lands (parcels) and grassland fields in that scale, where one arable land patch can contain more parcels (Donald et al., 2001; Hamer et al., 2006; Moreira et al., 2005; Perkins et al., 2000). According to Uuemaa et al. 2009 most bird species react more strongly to the composition land cover than to the configuration of landscapes (Uuemaa et al., 2009). Our results also show that the LULC proportions and mean patch sizes have stronger impacts on the abundance of this species, than the shape (fractal dimension index) characteristics of the habitat patches. The mean-absolute-percentage-error value (37.77%) was acceptable since, for a more precise prediction, we would have to use more variables (e.g., species and quantity of insects, used pesticides, parcel management) that are not accessible in country-scale analysis. We can determine that the landscape indices improved the model accuracy, based on the Table 5.4.

5.4.3. Predicted population inside the Natura 2000 SPAs

In Hungary, the latest estimated country-wide Eurasian skylark population is from 1999-2002. There is no spatially detailed population estimate. This study is the first estimate for Natura 2000 protected areas in Hungary. There some early 2000s studies about the skylark densities in Europe.

Table 5.5. Summary table of studies, which predicted the Eurasian skylark density inside European study areas

Study area	Estimated skylark density (individuals / km^2)	Reference
Natura 2000 SPA in Hungary	0-6.13	This study
Great Britain	1.97-7.45	Browne et al. 2000 (Browne et al., 2000)
Small study area in France	3.28-3.69	Eraud and Boutin 2002 (Eraud and Marie Boutin, 2002)
Spain	~5.21	Suárez et al. 2003 (Suárez et al., 2003)
Ireland	1.72	Copland et al. 2012 (Copland et al., 2012)
Northwest Ireland	4.87	Copland et al. 2012 (Copland et al., 2012)

The studies listed above do not use the shape and size related landscape indices for estimation of the skylark abundance (density). With the combination of the detailed point-based bird census data, detailed country-wide LULC dataset and landscape in-dices we can get a more precise prediction of skylark population. Our results are com-parable with these previous estimations and the density values are similar (Browne et al., 2000; Copland et al., 2012; Eraud and Marie Boutin, 2002; Suárez et al., 2003).

5.5. Conclusions

Landscape composition (proportions, and shape and size characteristics of LULC categories) has significant association with the skylark population. The salt steppes and meadows, and closed grassland serve as habitat for the Eurasian skylark. This study provides new information about the relationship between landscape metrics of the habitat types (shape and size characteristics of patches) and skylark abundance. Fractal dimension index, which describes the shape complexity of grassland patches has a positive impact on the skylark abundance, while the shape complexity of non-habitat types shows opposite relationships with the skylark density. We analysed them together and could estimate the association of these landscape composition variables (proportions, shape and size characteristics of LULC classes) with skylark abundance. We could estimate skylark population density inside Natura 2000 SPAs in Hungary.

The outcomes of this study can be used for further land use planning, and the habitat design of Natura 2000 SPAs and other protected areas of the rural landscapes. According to our findings, inside the protected areas should increase the proportion, the average size and shape complexity of those LULC types (arable land, salt steppes and meadows, and closed grassland), which shows positive relations with the abundance data of skylark. It is feasible by stopping the spontaneous reforestation and eradicating the spontaneously spread vegetation (especially invasive bush species). The grazing or mowing, the protected grasslands can preserve the size, shape and openness characteristics of these skylark habitats. This kind of environmental management forms help to conserve the habitat types of skylarks. The skylark is an area sensitive species and it is an indicator species of farmlands, so the shown methodology is adaptable for analysing the impact of landscape composition on other farmland bird populations (Achtziger et al., 2004; Butler et al., 2012; Hoffmann et al., 2016; Wakeham-Dawson, 1995). The skylark is considered as indicator for monitoring of agricultural landscapes, because its abundance shows strong relationships with other farmland bird species (Gippoliti and Battisti, 2017).

6. Investigation the relation between the recent land cover and the Eurasian skylark *(Alauda arvensis)* population changes in European scale

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Abstract

In Europe, the most widespread land cover category is agriculture, including non-irrigated arable land. The agricultural land cover category includes various types of land use with different levels of human impact. The heterogeneity and spatial structure of these landscapes vary among regions and countries, but the decline of farmland bird species population can be observed in almost all European countries. This decrease can be detected from the abundance data of farmland birds, such as the Eurasian skylark (Alauda arvensis). Some small-scale studies have analysed the relation between country- and regional-level land cover types and the population data of farmland birds. Europe-wide analysis is necessary to detect the land use land cover (LULC) types that are suitable habitat for the skylark and to compare the population density data of skylarks in Hungary and Schleswig-Holstein, with the Pan-European LULC datasets. In this study, we used the Corine Land Cover (CLC) 2012 dataset from the European Union and two (Hungarian and German) bird monitoring datasets were aggregated at the same grid size (5 × 5 km). Based on the CLC land cover dataset, we identified the land cover types of the Eurasian skylark habitat. We performed our statistical calculations by generalised linear models (GLMs) in R to determine the impact of land cover types on the abundance of skylarks. We applied negative binomial models to account for the over-dispersion of the skylark abundance data and the step AIC function with the stepwise function in both directions. In Hungary, we found a significant positive relation between skylark abundance and the Natural grassland LULC category and six significant negative relation s (e.g., Fruit trees and berry plantations; Complex cultivation patterns and Forests). In Schleswig-Holstein, we found significant positive relations between skylark abundance and Pastures and Natural grasslands. We identified the land cover types which shows positive relation s with skylark abundance as skylark habitat areas and the land cover types with negative relations with skylark abundance as skylark non-habitat areas. We calculated the habitat and non-habitat areas of the Eurasian skylark for each grid size (5 × 5 km) of CLC database and visualised the habitat changes between 2000 and 2018. We calculated habitat changes of European countries and compared it with the country level population change data of Eurasian skylark. Based on this he European-scale habitat change map of skylark we can detect habitat change hotspots of this farmland bird in European scale.

Keywords: Eurasian skylark; land cover; land cover change; habitat change; habitat change estimation; Corine Land cover

6.1. Introduction

In the XXI century, the dominant terrestrial ecosystem in the world is agriculture, including non-irrigated arable land, which accounts for 38% of all land cover (Fao, 2014). In Europe this value is much higher, at 45% (EBCC, 2020). The agricultural land cover of the rural areas includes various types of land use with different levels of human impact. The heterogeneity and spatial structure of agrarian landscapes vary among regions and countries, but the decline of farmland biodiversity can be observed worldwide. This decline can be detected in the abundance data of farmland birds (Morelli et al., 2020; Wretenberg et al., 2007). Many studies report that the decreasing trend in farmland birds has a significant relation with the intensive agricultural farming, landscape patterns and land cover diversity (Gil-Tena et al., 2015; Moreira et al., 2005; Orłowski and Ławniczak, 2009; Piha et al., 2003). Most articles focus on small-scale studies and analyse the relations between skylark abundance and crop type, height, coverage and heterogeneity (Berg et al., 2015; Gottschalk et al., 2010; Guerrero et al., 2012; Hoffmann et al., 2018; Praus and Weidinger, 2015; Redlich et al., 2018; Peter Szilassi et al., 2019). Some large-scale studies analyse the relations between country- and regional-level land cover types and the abundance data for farmland birds (Peter Szilassi et al., 2019). Europe-wide analyses are necessary to detect the land cover types that are suitable environment for the Eurasian skylark (Alauda arvensis). Here, we compare the habitat preferences of this farmland bird in the two study areas (Hungary and Schleswig-Holstein, North-Germany) based on Pan-European datasets. Analyses of these two study areas with different landscape characteristic are needed, because could vary the habitat preferences of skylark and there are different drivers of habitat changes across Europe.

The skylark is the most distinctive bird of the agrarian landscape in Europe. In the European Union, the Eurasian skylark has a declining trend in population between 2000 and 2018: Norway -47%, Lithuania -41%, France -38%, Czech Republic -29%, Hungary -24% and Germany -17%. Most skylarks leave Hungary and Germany to settle in the Mediterranean region for the winter time (Csörgo et al., 2009). The skylark was introduced into the Americas, Asia, Australia and New Zealand except the Nearctic and in high mountains (Cramp, 1988). The habitat preferences, including crop structure and heterogeneity, of the skylark are well-known. Large-scale studies have provided general knowledge about the skylark's continental- and regional-wide preferences for habitat and land cover heterogeneity (Peter Szilassi et al., 2019). However, only a few studies have analysed the relations between skylark abundance and land cover types across Europe, and fewer studies have estimated habitat changes on a European scale. To estimate changes in the skylark's habitat, first we have to identify the land cover types that serve as habitat for the skylark. The second step is to determine the impact of land cover changes on the skylark's abundance changes.

In this study we used the Corine Land cover 2012 (CLC 2012) dataset from the European Union and two bird monitoring datasets on regional scale. We used CLC 2012 to identify the land cover types of the skylark's habitat, and based on this dataset, we estimated the impacts of disparate land cover types on the skylark's population in Europe. Based on the model's results, we can describe the optimal landscape composition for this species in Europe. Our outcomes may be helpful for further researches of recent land cover changes related to this species in other countries. The skylark abundance data were acquired from the Hungarian Common Bird Monitoring (MMM) database and from the Ornithological Working Group of Schleswig-Holstein and Hamburg (Südbeck et al., 2005; Szép et al., 2012).

The following were the main goals of this study:

- To determine and analyse the impact of land cover types on the skylark's abundance on regional scale.
- To compare with each other the habitat changes and the skylark's population trend changes in European scale.

The results of this study are expected to be valuable for understanding the environmental background the changes in the abundance of the skylark. The results could also be useful for studying other situations or for analysis of the impact of landscape composition on the populations of farmland birds.

6.2. Materials and methods

6.2.1. Study area

Hungary is placed in Central Europe and in the Carpathian Basin (45°43' to 48°35'N and 16°06' to 22°53'E), which is part of the Pannonian biogeographic region (Figure 6.1). The country has an area of 93,033 km^2, and is characterized by an elevation between 77 and 1014 m a.s.l. The agricultural land is the most important land cover type, and 61% of the country is cultivated as non-irrigated arable land (Farkas and Lennert, 2015). An additional 20.7% consists of grassland and forest, and 5.5% consists of built-up areas.

Schleswig-Holstein Federal State is located in Northern Germany. This area is surrounded by the sea on east (North Sea) and west (Baltic Sea), and it is bordered by Denmark on the north (Figure 6.1). The most important land cover type is agricultural land, and 48% of the state is covered by non-irrigated arable land. An additional 38% is covered by grassland and forest and 8.5% is covered by built-up areas.

6.2.2. Databases

Abundance data of the skylark

In Hungary, a country-wide bird-monitoring survey has been conducted each year from 1999 by approximately 800 field surveyors. The establishment of the Hungarian Common Bird Monitoring Database (MMM) has been resulted by their work (Szép et al., 2012; Szép and Gibbson, 2000; Szép and Nagy, 2001). With 2.5 × 2.5 km UTM quadrants covering the whole country, it was delineated as a bird-monitoring mapping unit before the surveys. This article focuses on the grid cells. Point counts within a 100-metre radius from each point (25 points in each UTM grid cell with a minimum distance of 500 m) was carried out during two spring visits. Samplings were performed between mid-April and mid-June, with a minimum of 2 weeks between samplings. The counts were performed at the morning between 5 and 10 am when there was no rainfall and the wind speed was less than 5 m/s. Our bird abundance dataset fits in time to our land cover database from 2012. We ordered the neighbouring 4 quadrants into 5x5 km grid (178 grid) to generalized the Hungarian dataset to the same as the Schleswig-Holstein dataset (Table 6.1).

The survey of the skylark abundance data in Schleswig-Hosltein have been performed by the Ornithological Working Group of Schleswig-Holstein and Hamburg (Ornithologische Arbeitsgemeinschaft für Schleswig-Holstein und Hamburg). The data collection was maintained by the ADEBAR (Der Atlas Deutscher Brutvogelarten) project between 2005 and 2009. All the breeding bird species have been mapped in the federal state by the approximately 150 surveyors. Samplings were performed between end of March and May, with a minimum of 2 weeks between samplings. The survey was managed inside the border grid of TK25 (Topographic map 1:25 000), where the area of each unit is approximately 120 km^2 (Südbeck et al., 2005). Each TK25 unit was split into four 5 x 5 km grid cells (Südbeck et al., 2005). 646 5 x 5 km TK25 grid cells take place in Schleswig-Holstein, of which 380 were surveyed (59%). 207 grid cells have been used, which contains the latest population data from 2009.

Table 6.1. Descriptive statistics of the Eurasian skylark's bird monitoring datasets from Hungary and Schleswig-Holstein

Study area	**Number of grids**	**Area of grids (km^2)**	**Skylark abundance**				
			Minimum	Maximum	Total	Mean	SD
Hungary	178	4450	1	230	1617	9.1	21.38
Schleswig-Holstein	207	5175	1	375	8325	40.22	40.42

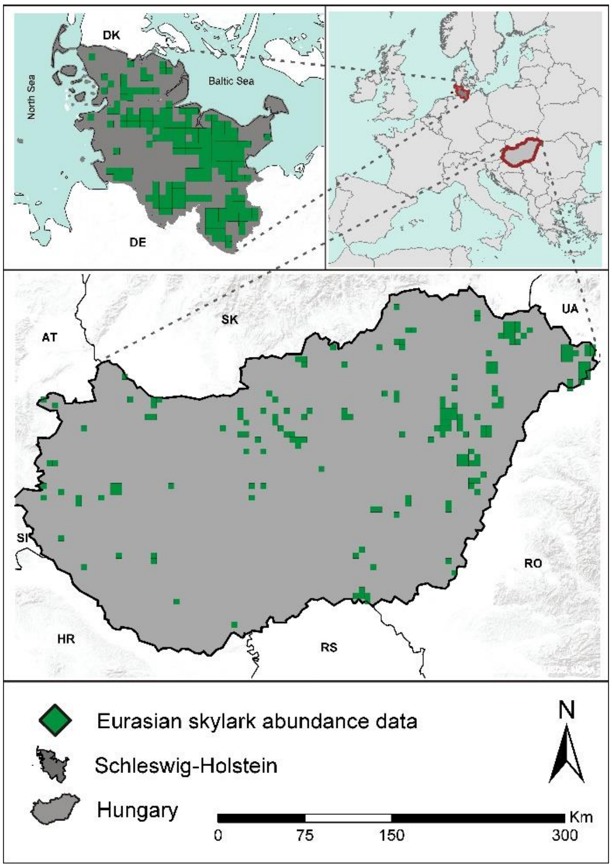


Figure 6.1. Study areas and spatial distribution of the grids, which contain Eurasian skylark abundance (number of grids: Hungary 175, Schleswig-Holstein 207)

CLC Database 2012

The Corine Land Cover datasets were produced using the same methods for all European Union countries (EEA, 2006; EEA and ETC-TE, 2017). The 1:100,000 scale datasets have a 25ha minimum mapping unit for patches and 100 m minimum width for linear elements. The first CLC dataset were prepared in 1990 and then it was repeated in every 6 years. 44 land cover and land use categories are included in the dataset, 30 categories are suited in Schleswig-Holstein and in Hungary there are 28 categories (EEA and ETC-TE, 2017). The study areas contain 21 level 3 CLC categories.

6.2.3. Data analysis

For our investigations we used the grids of the bird surveys from the two study areas in the same grid size (5 × 5 km). The proportion of land cover types (all CLC category) and the skylark population were determined inside the grids. There were no homogeneous landscapes inside the grids. We applied a preliminary test to identify the group of correlated land cover categories applying variance inflation factors (VIFs). The VIF values ranging between 1 and 1.8, which means that the explanatory variables were not linearly related, so the multicollinearity is low between the variables (LULC types and indices). We performed our statistical calculations by generalised linear models (GLMs) to determine the impact of land cover on the abundance of the skylark. The CLC 2012 dataset was used in the two study areas. In Hungary we used the CLC 2012 dataset and the abundance data from 2012. For Schleswig-Holstein we have abundance data from 2009 and CLC data from 2012, but they can be used together, because the landscape usually changes less than 1% per year (European Environment Agency, 2017). The Non-irrigated arable land category was not put into the model, because in Hungary and other European countries, the agricultural land is the matrix (dominant LULC type) in the landscape, so the proportion of this category shows strong autocorrelations with other LULC types. To account for the over-dispersion of the skylark population data, negative binomial models have been applied (tested by overdispersion test function of AER package in R). Models with all explanatory variables (CLC categories) were generated, and Akaike's information criterion has been used to rank them with the 'dredge' function of the 'MuMin' package in R (Barton, 2015). The 'LmerTest' package were used to determine he significance value of the variables (Kuznetsova et al., 2020). We also performed GLM using the stepAIC function with the stepwise function in both directions. In further analyses, we used the selected variables by the stepwise function. We constructed two groups from the land cover categories of the CLC database on the basis of GLM results, namely, preferred (significant positive relation) and nonpreferred (significant negative relation) land cover types.

Mean patch size and number of patches of all land cover types have been calculated to compare the landcover categories and to help understand the differences between the study areas and the results.

We estimated the habitat change of the skylark based on the CLC datasets from 2000 and 2018 in ArcGis 10.3. We generated a 5 × 5 km grid over all Europe where the CLC datasets available. We calculated changes in land cover types that were related to the skylark's abundance based on the GLMs, and the estimated habitat change was mapped in each grid cell. The following equation represents the calculation of the summarized skylark's habitat change in the grid cells (SHc):

$$(1)\ SHc = -\left(\sum cNH\right) + \sum cH$$

where *cNH* represents total changes non-habitat LULC types inside the grid and *cH* represents total changes in the habitat LULC types areas inside each grid cells respectively.

We used the Jenks natural breaks method (Jenks, 1967) to classify the summarized habitat changes into five classes: strong negative changes (from -2500 to -1123 ha), intermediate negative changes (from -1122 to -314 ha), minor negative changes (from -313 to 281 ha), intermediate positive changes (from 282 to 1067 ha) and strong positive changes (from 1068 to 2500 ha).

The relation between the bird population change (percent) and the habitat and non-habitat change (percent) by countries were calculated. Spearman's rank correlation analysis has been applied. The European common farmland bird index including the skylark trend was calculated by the data of Organisation for Economic Cooperation and Development (OECD); National BirdLife organisations. We analysed the correlation between the skylark's population trend and habitat decrease (HD), total habitat decrease and non-habitat increase (THD), total habitat increase and non-habitat decrease (THI). Following equations were used for the habitat change calculations:

$$(2)HD = \sum HD$$

$$(3)THD = \sum HD + \sum NHI$$

$$(4)THI = \sum HI + \sum NHD$$

where HD represents the total negative changes of habitat LULC types in each country; NHI represents the total positive changes of habitat LULC types in each country; HI represents the total positive changes of habitat LULC types and NHD represents the total negative changes of non-habitat LULC types in each country.

6.3. Results

6.3.1. Relations between skylark abundance data and land cover types in the study areas

We investigated the relations between skylark abundance data and land cover types in Hungary. Table 6.2 shows a summary of the results based on GLM models after the stepAIC function. Two land cover types were negatively correlated with skylark abundance at the 0.05 significance level: Fruit trees and berry plantations) and Complex cultivation patterns. Five land cover types were negatively correlated ($p < 0.001$) with skylark abundance: Construction sites, Green urban areas Broad-leaved forest), Coniferous forest and Inland marshes). Only one land cover type was positively correlated with skylark abundance ($p < 0.05$): Natural grassland

Table 6.2 also shows the relations between skylark abundance and land cover categories in Schleswig-Holstein on the basis of GLM models after the stepAIC function. We obtained results at different levels of significance. The Discontinuous urban fabric land cover type was negatively correlated with skylark abundance at $p < 0.001$, and two land cover types were negatively correlated with skylark abundance at $p < 0.05$: Mixed forest and Water bodies. Three land cover types were positively correlated with skylark abundance: Pastures (code 231, $p < 0.05$), Natural grassland ($p < 0.01$) and Inland marshes ($p < 0.05$).

The fourth column of Table 6.2 shows the land cover categories (green and red colours) that we have taken under consideration in the further European-scale analysis. The category of Inland marshes was positively correlated in Schleswig-Holstein and negatively correlated in Hungary with skylark abundance, and therefore we removed this category from further analysis.

Table 6.2. Summary table of CLC categories (in ha) showing the GLM results, estimated parameter values ± SD of each explanatory variable on skylark abundance

CLC name	Hungary			Schleswig-Holstein			In Eu-scale prediction
	Estimate	*SE*	*95% CI*	*Estimate*	*SE*	*95% CI*	
Discontinuous urban fabric	No significant relation			–0.027***	0.007	–0.04 to –0.014	–
Construction sites	–0.413*	0.186	–0.776 to –0.043	No significant relation			–
Green urban areas	–0.316*	0.135	–0.606 to –0.055	No significant relation			–
Fruit trees and berry plantations	–0.089**	0.029	–0.149 to –0.027	No significant relation			–
Pastures	No significant relation			0.006*	0.002	0.002 to 0.01	+
Complex cultivation patterns	–0.07**	0.022	–0.112 to –0.028	No significant relation			–
Broad-leaved forest	–0.012*	0.005	–0.021 to –0.002	No significant relation			–
Coniferous forest	–0.099*	0.042	–0.179 to –0.018	No significant relation			–
Mixed forest	No significant relation			–0.049*	0.022	–0.092 to –0.002	–
Natural grassland	0.008*	0.004	–0.001 to 0.017	0.073**	0.027	0.009 to 0.145	+
Inland marshes	–0.098*	0.039	–0.174 to –0.017	0.111*	0.053	–0.014 to 0.276	
Water bodies	No significant relation			–0.016*	0.007	–0.029 to –0.002	–
	Observations: 175; R^2 Nagelkerke: 0.386			Observations: 207; R^2 Nagelkerke: 0.371			

*$p < 0.05$, **$p < 0.01$, *** $p < 0.001$.
See Appendix 6.2 in the Appendix for detailed description of the Corine Land Cover categories.

6.3.2. Calculation of Eurasian skylark's habitat change in European scale between 2000 and 2018

Based on the results of the land cover type analysis and the habitat and non-habitat area calculations in the grids, we made a European-scale map of the skylark's habitat changes. The five LULC types show perfectly the changes in every country, and based on visual interpretation, we can identify the hot spots of habitat change. The countries most negatively affected by the skylark's habitat changes were Finland (–9.09%), the United Kingdom (–4.24%), Greece (–3.42%), Andorra (–3.35%), Slovakia (–3.2%), the Netherlands (–2.95%), Denmark (–2.65%), Switzerland (–2.27%) and Hungary (–2.2%). The changes are better described according to the components of habitat change. There are four components: habitat areas decrease, non-habitat areas increase, habitat areas increase and non-habitat areas decrease. The positive CLC categories changed the most in the negative direction in the United Kingdom (–9.91%), Andorra (–6.6%), Switzerland (–5.07%), Denmark (–4.99%), Germany (–4.97%), Ireland (–4.59%), Spain (–4.5%), Slovakia (–3.7%), Hungary (–3.68%) and the Netherlands (–3.5%). A high proportion of the LULC changed into habitat in Ireland (10.23%), the United Kingdom (5.23%), Romania (4.42). The values of the four components for each country are shown in Figure 6.2.

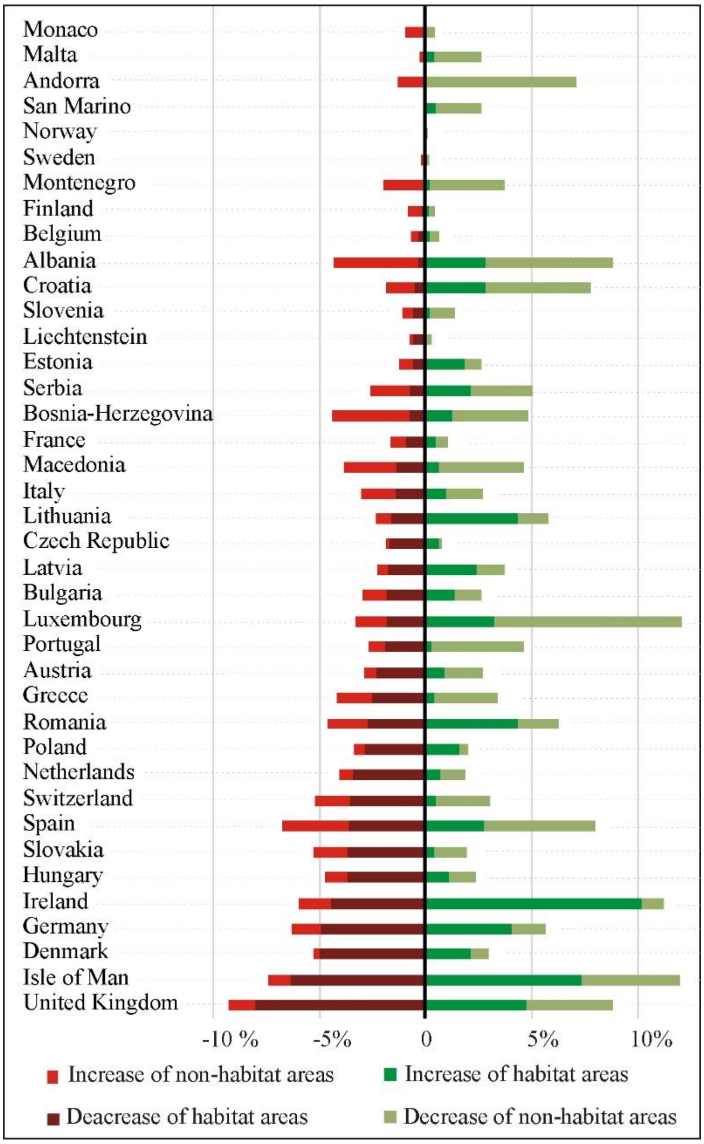


Figure 6.2. Changes in the habitat and non-habitat areas of the Eurasian skylark

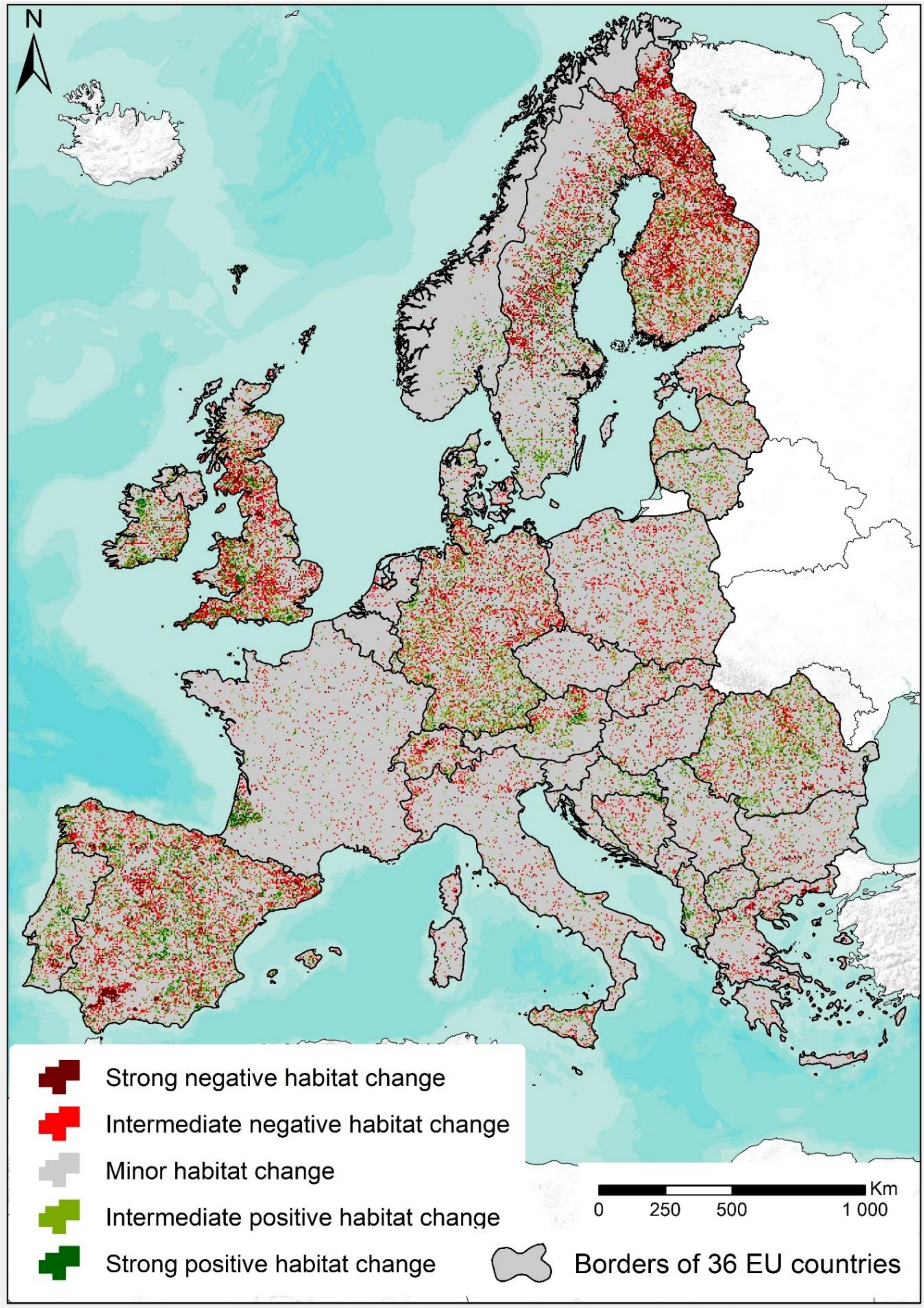


Figure 6.3. Estimated changes in habitat of the Eurasian skylark in 36 European countries between 2000 and 2018 based on GLM results and CLC 2000 and 2018 datasets.

The results map (Figure 6.3) shows the hotspots of habitat change at the country level. Many habitat declines can be found from east to west in the outer eastern Carpathians (Romania); in Finland close to the Russian border and the Lapland region; in Sweden, mostly in the Svealand region; in Schleswig-Holstein, Lower Saxony and Saxony in Germany; in the neighbourhood of Oxford and the south-west part of Scotland in the United Kingdom; between Bern and Zürich in Switzerland and in Catalonia and the Sevilla-Cordoba axis in Spain. The skylark's habitat increased in several regions in Europe: The Transylvania region in Romania, eastern Croatia, eastern Austria, southern Germany, southern England, southern (Cork) and Northern Ireland and Gascogne National Park in France. The result of correlation test between the skylark population changes and the estimated habitat change shows significant negative correlations, if the habitat areas decrease and the non-habitat areas increase (Table 6.3). The increase of habitat areas and decrease of non-habitat areas show a significant positive correlation with the skylark abundance data.

Table 6.3. Spearman's rank correlation between the estimated habitat changes and skylark population trend

	Habitat decrease	**Habitat decrease and non-habitat increase**	**Habitat increase and non-habitat decrease**
Trend of skylark population by countries	-0.528**	-0.553**	0.455*
Number of pairs	25	25	25
			*$p < 0.05$, **$p < 0.01$

6.4. Discussion

This study underpins the importance of general open-habitat changes of Eurasian skylark in Europe, suggesting that on-going land cover and habitat changes may strongly affect the distribution in most of its European range. We investigated the relations between land cover types and the abundance data of the skylark in two study areas in Europe. In the Hungarian study areas, the GLM based model between the skylark abundance data and LULC types in case of eight LULC types showed significant statistical connections. The skylark population data has significant relation with six LULC categories in Schleswig-Holstein (Germany). Habitat changes of the skylark in Europe has been modelled based on our results. The summarised LULC based habitat changes by countries are in accordance with the trends of the skylark population in each country. The habitat decline of the skylark was the strongest in the United Kingdom, Ireland, Germany, Denmark, Hungary, Slovakia and Spain.

6.4.1. Land cover types which show significant positive statistical relations with the skylark population

In case of the Hungarian study area, the Natural grassland LULC type was positively connected with skylark abundance. This LULC type is an important habitat area for farmland birds (Morelli, 2013). In central and eastern Europe, land abandonment has caused an increase in grassland, which is an important habitat for the skylark when it has not changed into scrub or bushy areas (Tryjanowski et al., 2011). There was no significant relation between skylark abundance and the Pastures category, because intensive grassland management in Hungary can be directly damaging to breeding skylarks (Koleček et al., 2015). Heldbjerg et al. 2018 found that the change from grazing to mowing caused significant decline in the trend of skylark in Denmark (Heldbjerg et al., 2018).

The results of German study area (Schleswig-Holstein) showed significant statistical connections s between skylark data and land cover categories in five LULC types. One of the most typical habitat of the skylark is pasture, because they are exposed to grazing, which maintains a low vegetation and homogeneous structure (moderate grazing does not disturb the skylark) (Cramp, 1988; Hoffmann et al., 2016; Koleček et al., 2015; Nagy et al., 2009). The Pastures and Natural grassland LULC types are suitable habitats if the height of the cover is less than 40 cm (Suárez et al., 2003).

We obtained different results in the selected two European study areas in Europe. Based on other studies (Tryjanowski et al., 2011), the differences are due to the different locations of the study areas in western and central-eastern Europe. There are differences between western and central-eastern Europe in the role of agriculture in the level of intensification (Tryjanowski et al., 2011). In Hungary, agriculture follows a mixed system, where intensive and traditional farming exist side by side (Báldi and Faragó, 2007). In Schleswig-Holstein, the size of the agricultural parcels differs in different parts of the state. The eastern part of the state is a traditional agricultural area with relatively large parcels. Land in the middle part is traditionally used as meadow and pastureland for livestock farming in small separated parcels, and the west has medium- and large-size arable land or grassland fields.

6.4.2. Land cover types which show significant negative statistical relations with the skylark population

We observed negative statistical connections between skylark abundance and seven CLC land cover categories in Hungarian study areas. The construction sites and Green urban LULC types. These two LULC category are part of the artificial surfaces first level CLC class. Construction sites are similar LULC categories to built-up areas, which also not habitat areas for the skylark because of the lack of natural features (Peter Szilassi et al., 2019; Szilassi, 2015). Fruit trees and berry plantation LULC categories were also negatively correlated with skylark abundance, because this category has dense vegetation coverage, which are properties that do not provide a suitable habitat for the skylark (Hoffmann et al., 2018; Praus and Weidinger, 2015). The skylark abundance significant negative relation with the Complex cultivation pattern may be due to the fact that the skylark does not prefer heterogeneous landscapes (Berg et al., 2015; Csikós and Szilassi, 2020; Gottschalk et al., 2010; Guerrero et al., 2012; Peter Szilassi et al., 2019). Berg et al., (2015), Gottschalk et al., (2010) and Szilassi et al., (2019) also established that there is a significant negative relation between the abundance data of skylark and the Forests LULC category (Broad-leaved and Coniferous). The dense forests areas decrease the openness of the landscape and has a negative association with the skylark population. Many studies highlight the importance of the landscape openness for the skylark (Morelli, 2013; Pedersen and Krøgli, 2017). The Water bodies category was also negatively correlated with skylark abundance, and it is well-known that this LULC category is not a preferred land cover type for the skylark.

In Schleswig-Holstein, the Discontinuous urban fabric LULC category was negatively correlated with skylark abundance. This land cover type is part of the artificial surfaces first level CLC class, and it is not a habitat area of the skylark because of the lack of natural features and the very fragmented landscape (Filippi-Codaccioni et al., 2008; Loretto et al., 2019). Filippi-Codaccioni et al., (2008) found a negative correlation between the proportion of urbanised area in 1 × 1 km grids and skylark abundance data. Skylark abundance was also negatively correlated with the Mixed forest LULC type; the reason is same as in case of other types of forests. The inland marshes category shows significant positive relation in Schleswig-Holstein because around the inland marshes there are lot of natural grassland area.

The proportions, number of patches and mean patch size of the land cover categories also differ, which can cause differences in the model results (Appendix 6.1). In Schleswig-Holstein there are more patches of Discontinuous urban fabric area with smaller mean patch size value and skylark do not prefer the fragmented landscapes by non-habitat areas. The same findings can be stated in the case of the forests.

6.4.3. European changes of Eurasian skylarks' habitat, and its relations with the skylark population

We could compare the summarized habitat and abundance changes of skylark in country level (Figure 6.2). Based on the calculated changes of the habitat and non-habitat land cover categories of the skylark, we could map the total summarized changes of skylarks' habitat in Europe (Figure 6.3). Figure 6.3 identifies the most significant spatial changes in skylark habitat at continental scale and highlights the habitat change hotspots in Europe. These hotspots may require further research, as United Kingdom, Ireland, Germany, Denmark, Hungary, Slovakia and Spain. For example, in northern Germany (Schleswig-Holstein and Hessen) there are confirmed changes in land cover that have a negative effect on the skylark population density (Csikós and Szilassi, 2020; Lüker-Jans et al., 2017). Heldbjerg et al., 2018 found that in Denmark, the population density of the skylark declined because of the new agri-environmental schemes (AES, 2001 - 2014) caused land cover changes (Heldbjerg et al., 2018). Daskalova et al., 2019 report the same phenomenon in Scotland, that the introduction of the new AES cause decline in farmland bird abundance trends (Daskalova et al., 2019). In Hungary, there is also a declining trend in abundance because of the reforestation of the grasslands and meadows (Peter Szilassi et al., 2019).

The result of Spearman's rho correlation test between the skylark abundance changes and the calculated habitat change between 2000 and 2018 shows significant positive statistical connections with each other (Table 6.3). It means that the recent habitat change of skylark shows significant statistical correlations with the population of the skylark. This result validates our results, but the extension of the input data with other parameters (landscape indices) could be improve the model accuracy of the recent skylark abundance changes.

6.5. Conclusion

Land cover types, which have positive and negative effects on skylark abundance, have been identified in both study areas, Hungary and Schleswig-Holstein. Based on the model results, we can divide the CORINE land cover categories into two groups, habitat and non-habitat categories. The habitat categories are Non-irrigated arable land (based on other studies), Natural grassland and Pastures. The non-habitat categories are Discontinuous urban fabric, Construction sites, Green urban areas, Fruit trees and berry plantations, Complex cultivation patterns, Broad-leaved Forest, Coniferous Forest, Mixed Forest and Water bodies. The habitat changes in the grid cells have been calculated, for an a European-wide map with 5 × 5 km grid cells. This map represents the habitat changes in the European scale, and based on this map, can be identify the hotspots of the positive and negative habitat changes. This study establishes the importance the openness of the-landscapes for this species in Europe, suggesting that on-going land cover and habitat changes may strongly affect the spatial distribution (density) of skylark in most of the European country.

7. Summary

In my thesis, I analysed the changes of the landscape, such as land cover, land use and landscape structure, in Hungary, Schleswig-Holstein Federal State and Europe, and their impact on a farmland bird (Eurasian skylark) abundance. These changes were driven by different causes in Western and Eastern-Central Europe, as the energy landscapes caused transformation (in Germany) or the reforestation of abandonment lands (in Hungary). I have analysed the impact of these changes on the abundance data of Eurasian skylark, because this bird is the indicator species of the agricultural landscapes. Based on these analyses, I was able to estimate the effect of the recent and long-term landscape changes on the fauna of agricultural lands, which is the main land cover category in Europe. I have drawn conclusions based on regional and local scale land cover and land use datasets.

I have selected the preferred (based on its positive significant connection with the skylark abundance) and non-preferred (based on its negative significant connection with the skylark abundance) land cover categories of the Eurasian skylark from the Corine Land Cover (CLC) database in Hungary. According to my results, the permanent crops (vineyards, fruit trees and berry plantations) and arable land CLC categories had a significant positive effect on the skylark population. According to the international literature, arable land is a well-known habitat type for this farmland bird species (Dietzen et al., 2014; Hoffmann et al., 2018, 2016; Praus and Weidinger, 2015). I observed similar results as the international references, that the pastures are the Eurasian Skylark's well-known habitat (Cramp 1988, Nagy et al. 2009, Kolecek et al. 2015, Hoffmann et al. 2016). Pastures are grazed, but moderate grazing intensity does not disturb ground-nesting farmland birds like the Eurasian Skylark, and it keeps the vegetation low and the habitat structure simple. According to my findings the recent abandonment of grasslands and the increasing land cover of dense bushes decrease the visual landscape openness, which could lead to a decrease in skylark populations. The most severe reduction in Skylark habitat occurred in central and western Hungary, where land abandonment and urban sprawl were the leading processes of recent land use change (Szilassi 2015).

According to my findings, the skylark population negatively correlated with the extension of scrub and/or herbaceous vegetation associations CLC category. Although Gottschalk et al. (2010) and Berg et al. (2015) discovered negative statistical connections between forest LULC categories and skylark abundance, I only found them inside 300 m and 600 m grain size (circle radius around the bird observation points), whereas the urban fabric and heterogeneous agricultural areas LULC categories showed a negative significant statistical relationship with skylark population inside all investigated buffer zones (300m, 600m and 1200m circle radius). According to my results the negative impact of forest land cover on the skylark’s occurrence can be explained by the dense and relatively high vegetation structure of forests, which reduces landscape openness and visibility.

My results are similar like other authors’ works which underlays the importance of openness of landscapes and land cover heterogeneity on farmland bird abundance (Gottschalk et al. 2010, Guerreo et al. 2012, Morelli et al. 2013, Pedersen & Krøgli 2017). Recent CAP generated LULC changes (afforestation and abandonment of poor-quality agricultural fields), together with urban sprawl, decline in grazing, and increasing landscape heterogeneity have resulted an increase in land cover types that skylarks do not prefer, which can be the cause of the species' recent decline in population (Verhulst et al. 2004, Báldi et al. 2005, Batáry et al. 2007, Báldi & Batary 2011, 2016, Szép et al. 2012).

In Schleswig-Holstein, I have delineated energy landscape units based on the bioenergy generated landscape transformations of rural landscapes. The existing biogas power plants (419 MW installed electrical capacity) in 2011 are mostly concentrated in the central and north-western glacial outwash plain of Schleswig-Holstein. Fields that were previously farmed with a diverse crop rotation now have higher shares of silage maize, especially when they are located near biogas power plants to reduce transportation distances and optimize economic production chain for biomass use (Delzeit et al., 2012; Delzeit and Kellner, 2013). From the early 2000s, the proportion of silage maize covered areas increased in the entire study area, increasing by around 90,000 ha, while pastures decreased by around 70,000 ha. The municipalities with the highest increases reached the 66% proportion of silage maize areas. Silage maize is, without a doubt, the most important indicator of the bioenergy-driven transformation of the agricultural landscape. The area of silage maize areas has the strongest positive correlation ($r = 0.572$; $p<0.01$) with biogas power plants density. The decrease in pasture area coincides with the start of increased silage maize growing. Other crop and land use types did not increase to the same proportion as silage maize, according to the land use dataset (Figure 7.1.).

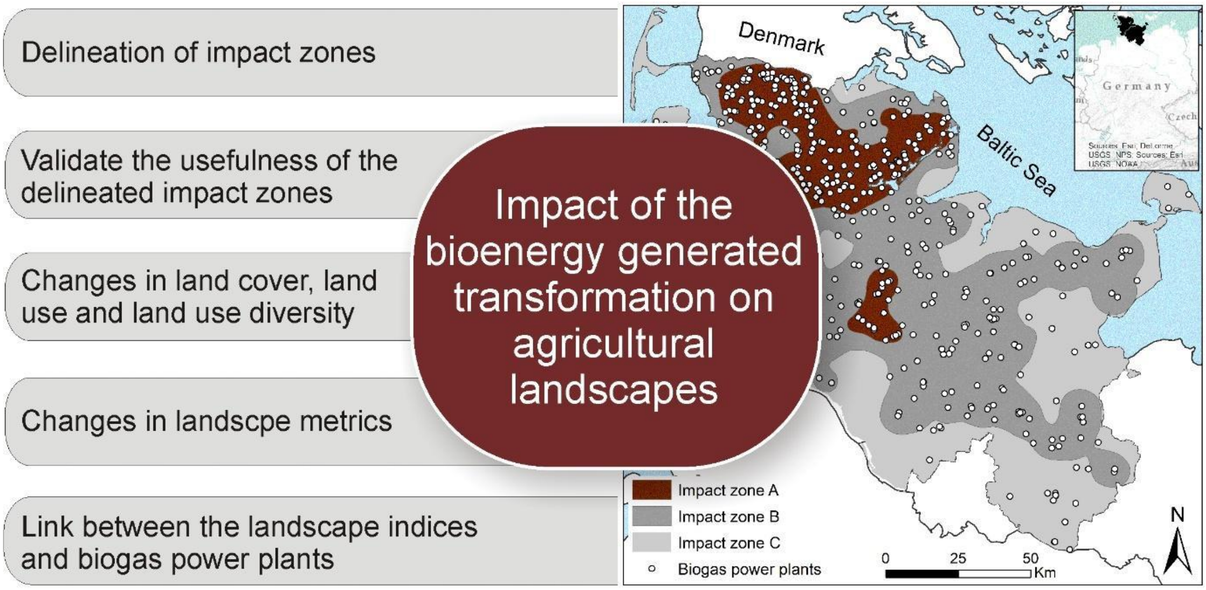


Figure 7.1. Drivers of the bioenergy generated transformation on agricultural landscapes, and the energy landscape units of the study area.

Comparing the two Corine Land Cover (CLC) data sets from 2000 and 2012 reveals that the arable land LULC patches became larger and complex, while the LULC patches covered with pasture became more compact shape characteristics, including a reduced length of their margins/edges. This is particularly true in areas with a high density of installed biogas power plants. These findings suggest that a greater proportion of arable fields are becoming larger, and more complex in shape, while fewer isolated patches of pasture remain. A decreasing trend in agricultural land cover diversity were demonstrated by comparing the land use data from 2003 and 2010. Considering crop diversity, a negative change in the Shannon diversity index, Shannon evenness index and Richness index were observed for the entire study area. This indicates that the increase in silage maize production subsequently replaces other crops that were originally grown in these landscapes, which contributes to a loss of crop diversity and a depletion of landscape diversity.

I analysed the energy landscape driven changes in Schleswig-Holstein and I also investigated the Eurasian skylark abundance relationship with these LULC changes. I analysed the relationship between skylark population data and CLC categories. Based on the GLM results, four land cover categories had significant relation with the skylark population data. The recent LULC changes are being influenced by the new biogas energy landscape. The area of pastures has been drastically reduced as a result of the introduction of biogas plants (especially silage maize) (Lüker-Jans et al., 2017). The results of the landscape change are the aggregation of small parcels into homogeneous large silage maize fields without shrubs and natural grassland corridors and the decrease of landscape heterogeneity. I have discovered a negative significant correlation between the Shannon Diversity Index (SDI) of landscape and the skylark population dataset. My findings show that increasing landscape heterogeneity has a negative impact on the population of the Eurasian skylark at the regional (CLC) scale, which confirms other studies (Berg et al., 2015; Gottschalk et al., 2010; Guerrero et al., 2012; Redlich et al., 2018). The permanent crops LULC category has a negative correlation with the skylark abundance, and it ranks second in the model, implying that it has a significant impact on skylark population. The height and coverage of vineyards and fruit plantations, which are not suitable habitats for this bird species, are most likely responsible for the negative correlation (Figure 7.2.) (Hoffmann et al., 2018; Praus and Weidinger, 2015).

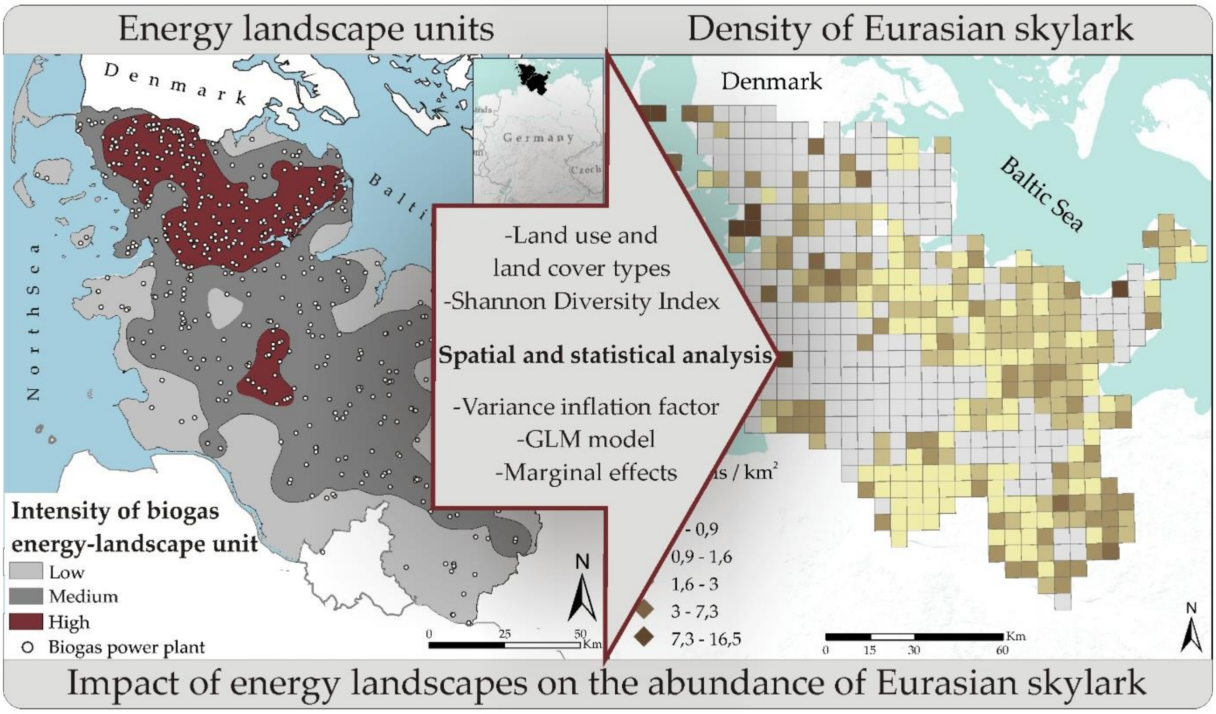


Figure 7.2. Impact of biogas energy landscapes on the density of Eurasian skylarks in Schleswig-Holstein Federal State

In the entire study area, I have also discovered a negative correlation between the areas of winter rape and silage maize and the Eurasian skylark population density. Based on the findings of Hoffmann et al. (2018), silage maize and winter rape can provide a suitable habitat for the Eurasian skylark during the early breeding period, but later, as these plants grow too high and the ground coverage becomes too dense, this type of area will no longer be suitable during the breeding periods. According to my multimodel estimate, winter rape has the most negative impact on the skylark abundance. This bird species is also negatively affected by the high heterogeneity of agricultural land, i.e., crop types. Previous research has looked into the relationship between crop heterogeneity and skylark abundance, in England, skylark density increased with habitat heterogeneity, according to Chamberlain et al. (1999); however, farmland plots in the lowlands of England showed decreased skylark density as habitat heterogeneity increased. These findings suggest that crop type matters more than crop heterogeneity value for the skylark population. An increase in bioenergy crop cultivation within the biogas energy landscape, according to Blaschke et al. (2013), will reduce land availability for traditional agriculture and nature conservation. Based on the predicted marginal effects method, I was able to identify crop types that had a positive (potato and sugar beet) or negative (silage maize, permanent crops, and rape) impact on the abundance of this bird species. In addition, I ranked the variables according to their importance in GLM models. I conclude that the introduction of energy crops (silage maize) and the homogenization process of the energy landscape have a negative impact on the Eurasian skylark population throughout Schleswig-Holstein Federal State.

I have investigated the connection between LULC and skylark population not only based on a regional scale land cover database (CLC), but I also used a local scale, more detailed, high resolution LULC dataset. The Hungarian ecosystem basemap offers a unique opportunity to use a detailed land cover dataset in country scale analysis and to compare the results based on different land cover datasets. Using this high resolution (20 m X 20 m) LULC dataset, I have also identified the skylark preferred and non-preferred LULC categories. It gives the chance to analyse the scale sensitivity of different source land cover datasets, like Corine Land Cover and Hungarian Ecosystem Basemap. Non-preferred LULC types had negative significant relations with skylark abundance. These were built-up and green urban areas with a high proportion of artificial surfaces that had a negative impact on the population due to a lack of openness and these findings are confirmed by other international publications (Gottschalk et al., 2010; Guerrero et al., 2012). The skylark abundance data has a negative significant relationship with the complex cultivation pattern land cover type. According to other authors, skylarks do not prefer heterogeneous agricultural lands because this rural landscape contains a variety of LULC patches, including those that skylark does not prefer, such as vineyards, fruit and berry plantations (because of its height) (Berg et al., 2015; Redlich et al., 2018). There are exists many forest LULC types in the HEB dataset, but I did not differentiate between them, because according to previous researches, none of the forest area types are considered habitats for this species.

Grassland and pasture areas are well known habitat types of skylarks (Hamer et al., 2006; Koleček et al., 2015; Moreira et al., 2005; Piha et al., 2003; Reif and Hanzelka, 2016). The novelty of my results is that the LULC categories of salt steppes and meadows, as well as closed grasslands, had a significant positive relationship with skylark abundance and other grassland types have no connection with skylark population. Because of the medium vegetation height and optimal proportion, each LULC category is suitable habitats for skylarks.

According to my findings, landscape metrics of preferred LULC types show positive significant relationship with skylark abundance, implying that if arable-land and grassland proportion and shape complexity were higher, the skylark population would be higher as well. The skylark population density was found to have a negative significant relationship with the landscape metrics of the non-preferred LULC types, indicating that skylark population density would be higher in landscapes with small size and compact shape of non-preferred LULC categories (built-up area, complex cultivated areas, forests, permanent croplands and water surfaces).

According to my findings, the EU agri-environmental policy should pay more attention to the management of salt steppes and meadows, as well as closed grasslands, for the prevention of farmland bird habitats. To increase skylark population density, the average LULC patch size and proportion of these land cover types in the landscape (compared to all) should both increase. One of the most serious ecological issues in protected grassland areas is the spontaneous spread of bush vegetation, which threatens skylark habitats. For the protection of skylark habitat, it should be reducing the size and shape of the bush and forest LULC patches inside these grasslands dominated areas if we want to keep the landscapes open. As a result, the local farmers must use proper grazing or haymaking techniques to eradicate the naturally spreading bush vegetation (which is often invasive species). This type of protected area management not only helps to preserve the diversity of grasslands' vegetation, but it also helps to protect the skylark's habitat. According to Uuemaa et al. 2009, most bird species are more sensitive to land cover composition (proportions of the different LULC types) than to landscape configuration (shape and size characteristics of different LULC types) (Figure 7.3.). According to my results, the application of landscape metrics into the model increased the precision of the skylark population data estimation (mean percentage error value decreased from 46.56% to 37.77%). The estimated population density values (0-6.13 individuals/km^2) fits to the results of international publications (1.72-7.45 individuals/km^2) (Browne et al., 2000; Copland et al., 2012; Eraud and Marie Boutin, 2002; Suárez et al., 2003).

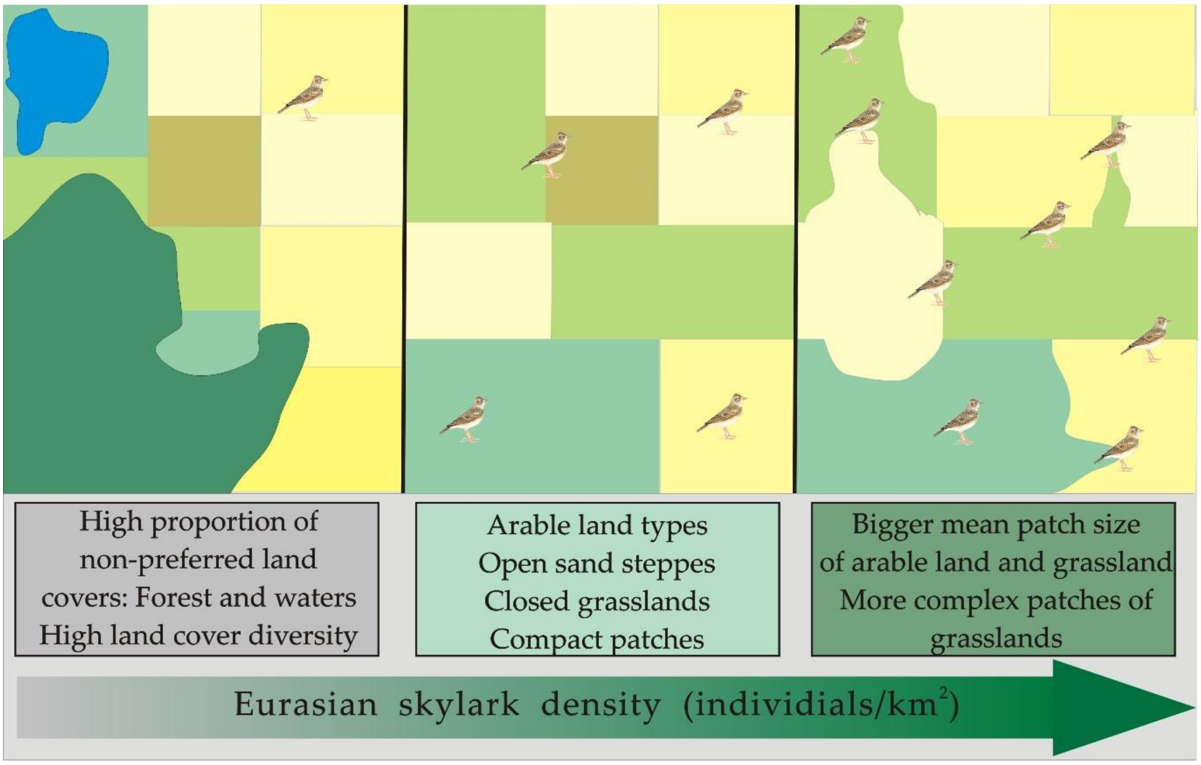


Figure 7.3. Proper landscape composition and configuration for the Eurasian skylark habitat

Because the skylark is a habitat (landscape) sensitive species, it is also used as an indicator in monitoring of this agricultural bird (Gippoliti and Battisti, 2017). The showed methodology can be used to investigate the impact of landscape composition on other farmland bird populations and estimate population size where there is no data on bird abundance.

I investigated the significance of general open-habitat changes in Europe and the ongoing land cover and habitat changes may have a significant impact on the species' distribution across most of its European range. Based on two study areas in Europe, I looked into the relationships between land cover types and skylark population data. The GLM-based model between skylark abundance data and LULC types in the Hungarian study areas revealed significant statistical connections in the case of eight LULC types (Construction sites, green urban areas, fruit trees and berry plantations, complex cultivation patters, broad-leaved forests, coniferous forests, natural grasslands and inland marshes). In Schleswig-Holstein, skylark population data shows a significant relationship with six LULC categories (Discontinuous urban fabric, pastures, mixed forests, natural grasslands, inland marshes and water bodies).

According to my findings there was no significant relation between skylark abundance and the pastures LULC category, because intensive grassland management in Hungary can be directly damaging to breeding skylarks. According to Heldbjerg et al. (2018), the switch from grazing to mowing resulted a significant decrease in the trend of skylarks' population in Denmark. Based on my results in the Schleswig-Holstein study area, one of the most typical habitats (preferred LULC types) of skylark is pasture, because these areas are exposed to grazing, which maintains low vegetation and a homogeneous structure (moderate grazing does not disturb the skylark) (Cramp, 1988; Hoffmann et al., 2016; Koleček et al., 2015). In the two European study areas I got different results. The differences can be explained, according to other studies (Tryjanowski et al., 2011), by the study areas' different locations and different level of agricultural land use intensification in Western and Central-Eastern Europe.

Based on the calculated changes in habitat (skylark preferred) and non-habitat (skylark non-preferred) LULC categories, I was able to compare the changes in skylark habitat and population at country level and to map the total summarised changes in skylark habitat in European scale. The habitat change hotspots in Europe are highlighted in Figure 6.3, which shows the most significant spatial changes in skylark habitat at a continental scale. The United Kingdom, Ireland, Germany, Denmark, Hungary, Slovakia, and Spain are among the hotspots. For example, there are confirmed changes in land cover in northern Germany (Schleswig-Holstein and Hessen) that have a negative impact on skylark population density (Csikós and Szilassi, 2020; Lüker-Jans et al., 2017). According to Heldbjerg et al., the population density of the skylark in Denmark has decreased as a result of new agri-environmental schemes (AES, 2001-2014) that have resulted in land cover changes (Heldbjerg et al., 2018). Daskalova et al., 2019 report the same phenomenon in Scotland, claiming that the new AES has resulted decrease in farmland bird abundance trends (Daskalova et al., 2019). The population of skylarks has shown significant statistical correlations with recent habitat changes. This result confirms my findings, but according to my results the addition of other parameters (landscape indices) to the input data could improve the model's accuracy in predicting recent skylark population changes.

In summary, based on the results of my thesis, I can establish that European land cover and land structure changes strongly influence the avifauna of the agricultural landscapes. Across Europe, there are different drivers of the LULC change in West and Central-East Europe. I could observe several hot spots of the Eurasian skylark's habitat change, from which negative changes (which can be related to the skylark population decline) are the dominant. Based on the results of the two investigated study areas, Hungary and Schleswig-Holstein, I could quantitatively estimate the habitat changes of the Eurasian skylark.

According to my findings in Hungary, in the last two decades, land abandonment and reforestation were the main drivers of land cover change. The proportion of pastures and permanent crops inside the all investigated grain sizes (buffer zones) showed significant positive statistical relationships with the population data of the Eurasian Skylark on a regional scale (based on the CLC database). The urban fabric and heterogeneous agricultural LULC categories, according to my findings, are not grain size dependent variables, implying that their land cover types have negative significant relationships with Skylark abundance at all investigated distances (inside 300 m, 600 m, 1200 m radius buffer zones). According to my predictions, the habitat loss of the Eurasian Skylark will continue at least until 2050.

In Western-Europe, such as in Schleswig-Holstein Federal State, the energy landscapes generated by land cover transformation cause a decline in the abundance of agricultural fauna. Biogas power plants have the potential to alter the size and shape of former pasture lands while also increasing the area, size, and complexity of arable land patches. Large homogeneous energy crop fields strongly decrease the heterogeneity of the landscape and the agricultural land.

Land cover and crop heterogeneity had negative impacts on the population of the Eurasian skylark. I identified crop types that had either a positive (potato and sugar beet) or negative (silage maize, permanent crops and rape) impact on the abundance of this bird species. I can state that introduction of energy crops (silage maize), and the homogenization process of the energy landscape have had a negative effect on the population of the Eurasian skylark in case of Schleswig-Holstein.

The salt steppes and meadows, and closed grassland serve as habitats (preferred LULC types) for the Eurasian skylark in Hungary. The fractal dimension index, which describes the shape complexity of grassland patches has a positive impact on the skylark abundance, while the shape complexity of non-habitat types shows opposite relationships with the skylark population density. The estimation of the Eurasian skylark density can be achieved with a low error range. Protected areas should increase the proportion, the average size and shape complexity of arable land, salt steppes and meadows, and closed grassland to preserve the agricultural land's related species habitats such as skylark.

In my thesis, I have investigated the feasibility of estimating the number of skylark individuals at different scales of land cover maps. My results can be important for estimating 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 the thesis can be also important from the point of view of landscape planning, as they can be used to design a new landscape structure (composition) in protected areas that are suitable and favourable habitats for farmland birds, especially skylarks.

8. Összefoglaló

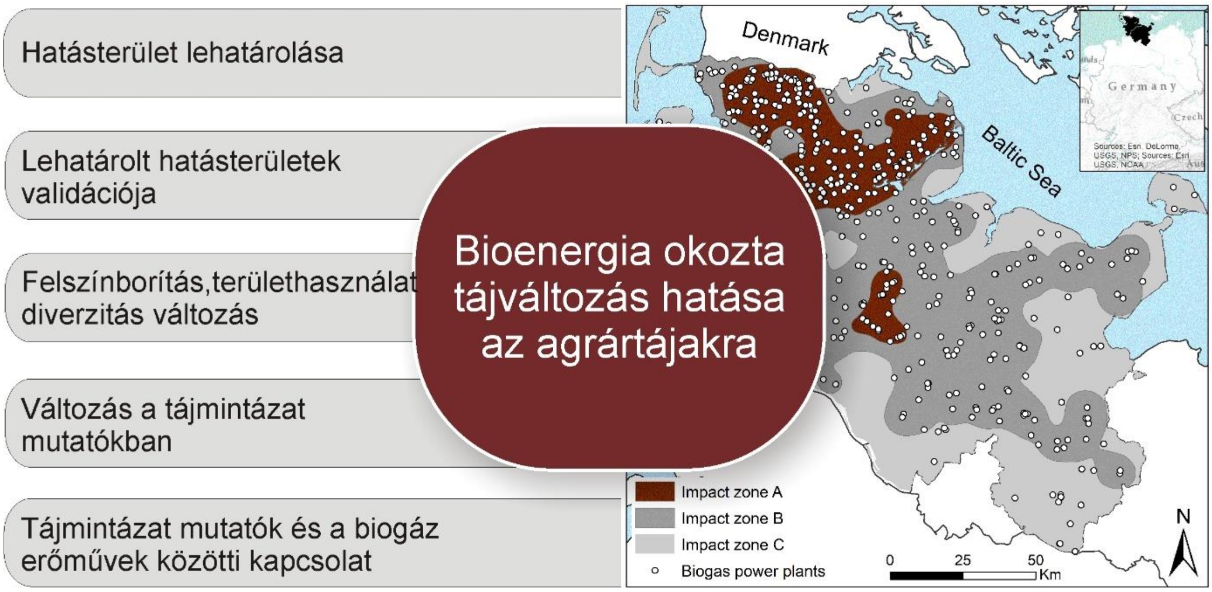
Dolgozatomban a felszínborítás, a területhasználat, a tájszerkezet változásait elemeztem Magyarországon, Schleswig-Holstein tartományban és Európában, és e változások kapcsolatát a mezei pacsirta előfordulási adataival. Ezeket a változásokat Nyugat– és Közép-Kelet-Európában különböző okok vezérelték, mint például a mezőgazdasági területek energia tájakká történő átalakulása (Németországban) vagy a felhagyott területek spontán erdősödése (Magyarországon). E táji változások hatását elemeztem a mezei pacsirta abundancia adataira, mivel ez a madárfaj a mezőgazdasági tájak indikátorfajának tekinthető. Elemzéseim alapján meg tudtam becsülni ezeknek a közelmúltbeli és hosszú távú tájváltozásoknak a hatását Európa fő felszínborítási kategóriájára: a mezőgazdasági területek faunájára. Következtetéseimet regionális és lokális felszínborítás– és területhasználati adatsorok alapján vontam le.

A magyarországi Corine Land Cover (CLC) felszínborítás-adatbázis alapján meghatároztam a mezei pacsirta által kedvelt (pozitív szignifikáns kapcsolat) és nem kedvelt (negatív szignifikáns kapcsolat) felszínborítás-kategóriákat. Eredményeim szerint az szőlőterületek, gyümölcsfák és bogyósgyümölcs-ültetvények és a szántóföldek CLC-kategóriái szignifikáns pozitív hatással voltak a pacsirta jelenlétére, ezeken a területeken magasabb e faj egyedszáma. A szakirodalom szerint a legelők a mezei pacsirta jellegzetes élőhelyei (Cramp 1988, Nagy et al. 2009, Kolecek et al. 2015, Hoffmann et al. 2016). A mérsékelt intenzitású legeltetés nem zavarja az olyan talajon fészkelő madárfajokat, mint a mezei pacsirta, mivel a növényzet magasságát alacsonyan tartja, valamint az élőhely szerkezetét is megőrzi. A legelők felhagyása és a spontán növekvő bozótosok felszínborítása növeli a táj zártságát, ami a pacsirta populációcsökkenéséhez vezethet. A pacsirta élőhelyének legdrasztikusabb csökkenése Közép és Nyugat-Magyarországon következett be, ahol a közelmúltbeli területhasználat-változás vezető folyamata a szántóterületek felhagyása, (művelés alóli kivonása) és a városiasodás volt (Szilassi 2015).

Eredményeim szerint a pacsirta egyedszáma negatívan korrelált a cserjés és/vagy lágyszárú növénytársulások (beleértve a természetes gyepterületeket is) felszínborítás kategóriáinak kiterjedésével az általam vizsgált tájablakokon (a megfigyelési pontok 300m, 600m és 1200m-es sugarú pufferein belül). Ezt a természetes gyepszukcessziós folyamatokkal magyarázhatjuk, hiszen ezek többnyire felhagyott szántóterületek, amelyek mostanra cserjés területekké alakultak át. A természetes gyepterületek nyitottsága csökken a szántóföldek felhagyásával és a legeltető állattartás visszaszorulásával. Bár Gottschalk et al. (2010) és Berg et al. (2015) negatív statisztikai kapcsolatot fedeztek fel az erdők felszínborítás-kategóriája és a pacsirta egyedszáma között, én ezt csak a 300 m-es és 600 m-es tájablakon belül állapítottam meg (a madármegfigyelési pontok körüli puffer), míg a "városi zöldterület" és a "heterogén mezőgazdasági területek" felszínborítási kategóriák minden vizsgált tájablakon belül negatív szignifikáns statisztikai kapcsolatot mutatnak a pacsirta egyedszámával. Az erdőfoltok negatív hatása a mezei pacsirta egyedszámára az erdők sűrű és viszonylag magas növényszerkezetével magyarázható, amely csökkenti a táj nyitottságát és a láthatóságot.

Számos tanulmány kiemelte a táj nyitottságának és a felszínborítás heterogenitásának jelentőségét a szántóföldi madarak élőhely viszonyaival, egyedszámával kapcsolatban (Gottschalk et al. 2010, Guerreo et al. 2012, Morelli et al. 2013, Pedersen & Krøgli 2017). A közelmúltbeli erdősítés és a rossz minőségű mezőgazdasági területek felhagyása, a városiasodás, az állattartás (legeltetés) visszaszorulása és a táj heterogenitásának növekedése a mezei pacsirta által nem kedvelt felszínborítás-típusok növekedését eredményezte, ami, más szerzők munkáival is összhangban álló eredményeim szerint a faj egyedszámának közelmúltbeli csökkenéséhez vezethetett (Verhulst et al. 2004, Báldi et al. 2005, Batáry et al. 2007, Báldi & Batary 2011, 2016, Szép et al. 2012).

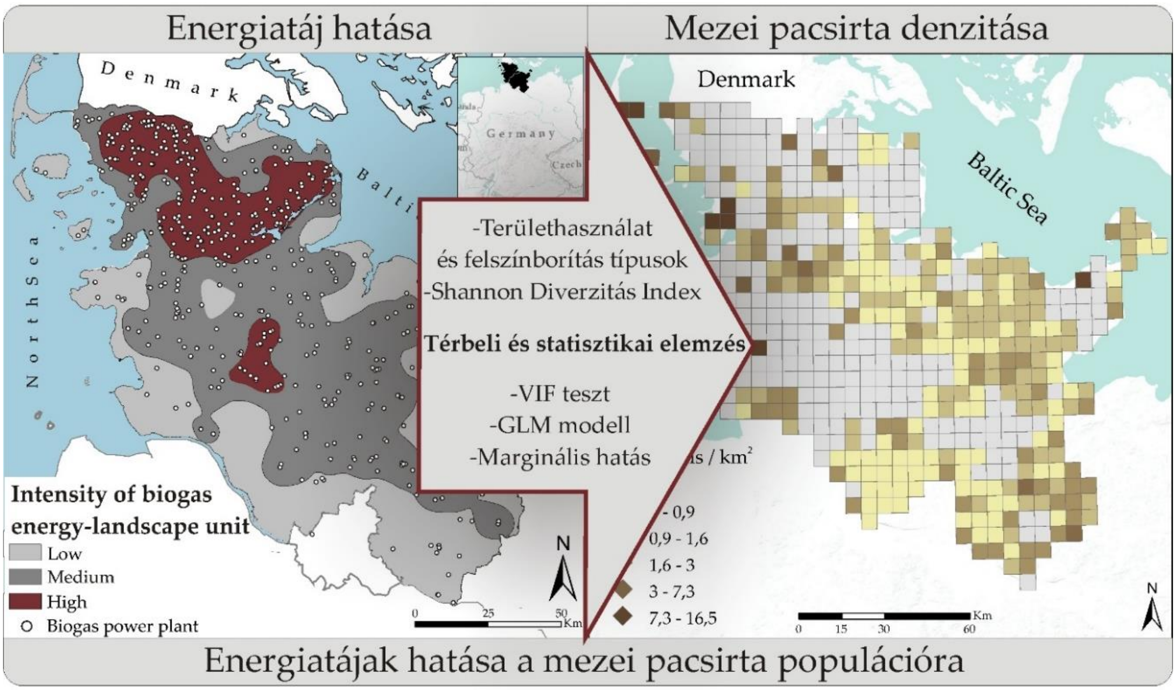
A Schleswig-Holstein tartományi mintaterületen azokat a táji egységeket (energiatáj-egységeket) határoltam le, ahol (különböző intenzitással) a bioenergia bevezetése okozta tájváltozás végbement. A 2014-ben működő biogázerőművek (419 MW beépített elektromos kapacitás) többnyire Schleswig-Holstein középső és északnyugati morénasíkságain helyezkednek el. A korábban változatos vetésforgóval művelt szántóföldeken ma már kiemelkedően magas a silókukorica aránya, különösen a biogázerőművek közelében elhelyezkedő területek esetében mivel így csökkentik a szállítási távolságokat és ez által optimalizálják a bioenergia termelési láncot (Delzeit et al., 2012; Delzeit és Kellner, 2013). A 2000-es évek elejétől a silókukorica területi aránya a teljes mintaterületen nőtt, mintegy 90 000 hektárral, míg a legelőké 70 000 hektárral csökkent. A legnagyobb növekedést mutató területeken a silókukorica aránya elérte a 66%-ot, tehát a silókukorica kétségtelenül a legfontosabb mutatója a mezőgazdasági tájak átalakulásának. A silókukorica területnövekedése a legerősebb pozitív korrelációt mutatja a biogázerőművek sűrűségével az összes mezőgazdasági területhasználat típus és gabonafélék közül ($r=0,572$; $p<0,01$). A legelőterület csökkenése egybeesik a silókukorica területek növekedésével. Az egyéb növénykultúrák és területhasználati típusok az adatbázis alapján nem növekedtek a silókukoricával azonos mértékben (8.1. ábra).



Ábra 8.1. Bioenergia okozta tájváltozás hatása az agrártájakra Schleswig-Holstein mintaterületen

A 2000 és 2012 közötti CLC-adatsor összehasonlítása alapján kimutattam, hogy a szántóföld felszínborítás foltok nagyobb méretűek és összetettebb (komplexebb) alakúak lettek, míg a legelővel borított felszínborítás foltok kompaktabb alakúvá váltak, beleértve a szegélyek/szélek hosszának csökkenését. Ez különösen igaz azokra a területekre, ahol a biogázerőművek sűrűsége nagy. Eredményeim arra utalnak, hogy a szántóföldek egyre nagyobb hányada kapcsolódik egymáshoz, nagyobb és összetettebb alakúvá válnak, miközben kevesebb, és egymástól elszigetelt gyep és legelőfolt marad a tájban. A mezőgazdasági földterületek diverzitásának csökkenő tendenciáját a Schleswig-Holstein mintaterületre vonatkozó 2003-as és 2010-es területhasználati adatok összehasonlítása lapján mutattam ki. A termények diverzitását bemutató Shannon-féle diverzitás index, a Shannon-féle Evenness index és a Richness index negatív változása figyelhető meg a teljes mintaterületen. Ez azt jelzi, hogy a silókukorica-termesztés növekedése nagymértékben helyettesíti az eredetileg e tájakon termesztett más növényeket, ami hozzájárul a terménydiverzitás és felszínborítás heterogenitásának csökkenéséhez, a táj felszínborítás, ezáltal tájképi homogenitásának növekedéséhez. Ezek az eredmények összhangban vannak Jerrentrup et al. (2017) közzétett eredményeivel.

Elemeztem az energiatájak okozta táji változásokat Schleswig-Holstein tartományban, valamint statisztikai módszerekkel összehasonlítottam egymással a mezei pacsirta egyedszámának változását és a 2000-es évek eleje óta végbement felszínborítás változásokat. Elemeztem a pacsirta egyedszáma és a CLC-kategóriák közötti kapcsolatot. A GLM eredményeim szerint négy felszínborítás kategória áll szignifikáns kapcsolatban a pacsirta egyedszám adataival. Pozitív szignifikáns kapcsolatot találtam a legelő kategória és a pacsirta egyedszáma között – ahogy ez várható is volt, mivel a legelő a mezei pacsirta tipikus élőhelye (Cramp, 1988; Hoffmann et al. 2016). Kimutattam, hogy Schleswig-Holstein mintaterületen a közelmúltban végbement területhasználati / felszínborítási változások fő mozgatója a korábbi agrártáj biogáz alapú energiatáj felé történő átalakulása volt. Eredményeim szerint a legelők területe drasztikusan csökkent a bioenergia-növények (különösen a silókukorica) bevezetésének következtében, és ezt más szerzők is alátámasztják (Lüker-Jans et al., 2017.). A kis parcellák homogén, nagy silókukorica-földekké történő alakulása (aggregációja) következtében pedig – cserjék és természetes gyepfolyosók nélkül – a táj heterogenitása is csökkent. Negatív szignifikáns korrelációt mutattam ki táj szinten értelmezett Shannon-féle diverzitási index (SDI) és a mezei pacsirta egyedszáma között. Eredményeim azt mutatják, hogy a növekvő táji heterogenitás regionális (CLC) léptékben negatív hatással van a mezei pacsirta populációjára, ami megerősíti más szerzők eredményeit is (Berg et al. 2015; Gottschalk et al., 2010; Guerrero et al., 2012; Redlich et al., 2018). Eredményeim szerint az állandó növényi kultúrák CLC felszínborítási kategóriája negatív korrelációt mutat a pacsirta populációval, valamint a modellben a második helyen áll, ami azt jelenti, hogy jelentős hatással van a pacsirta egyedszámára. A negatív korrelációt valószínűleg a szőlőültetvények és gyümölcsösök magassága és a növényzet sűrűsége okozza, amelyek nem megfelelő élőhelyek e madárfaj számára, mivel csökkentik a táj nyitottságát (8.2. ábra) (Hoffmann et al. 2018; Praus és Weidinger, 2015).



Ábra 8.2. Energiatájak (biogáz) hatása a mezei pacsirta egyedszámára Schleswig-Holstein Tartományban

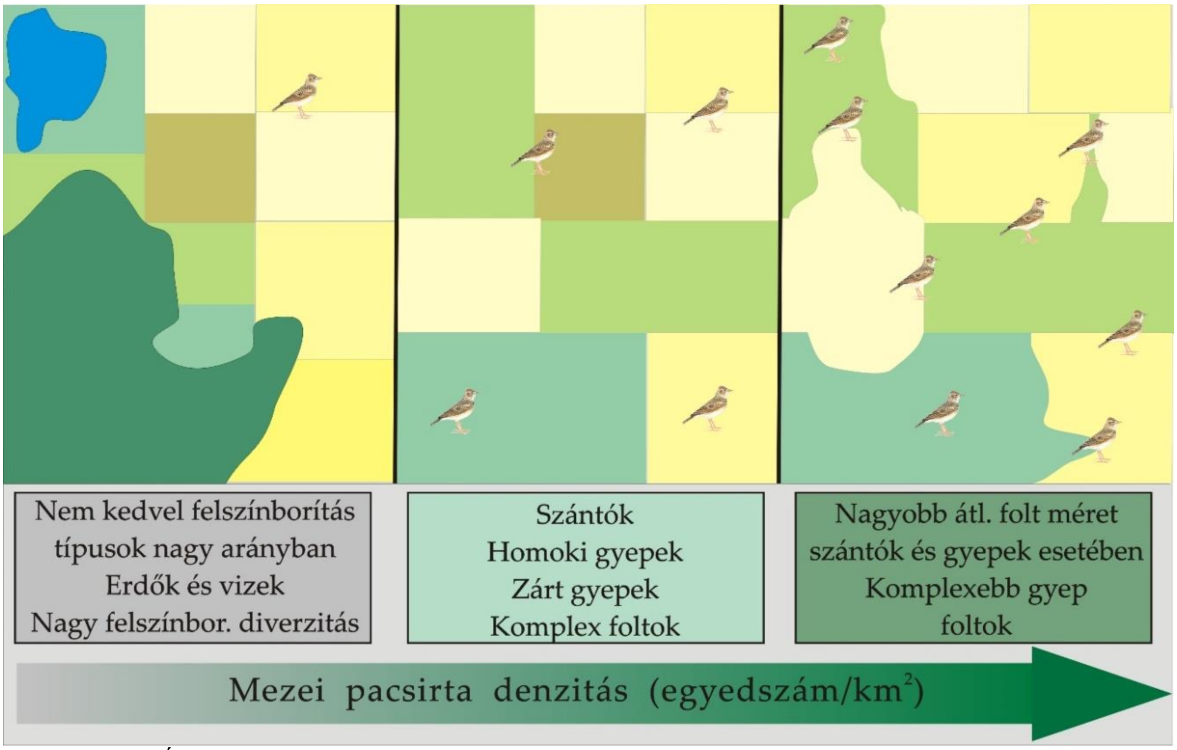
A teljes Schleswig-Holstein mintaterületen negatív korrelációt mutattam ki az őszi repce és a silókukorica, valamint a mezei pacsirta populációja között. Bár Hoffmann et al. (2018) eredményei alapján a silókukorica és az őszi repce a korai költési időszakban megfelelő élőhelyet biztosíthat a mezei pacsirta számára, de később ezek a növények túl magasra nőnek, a talajborítás aránya túl nagy lesz, és alkalmatlanná válik költésre. Multimodell becslésem szerint az őszi repcének van a legnagyobb negatív hatása a vizsgált madárfaj egyedszámára. Kimutattam, hogy a pacsirta egyedszámát a mezőgazdasági területek nagymértékű termény-heterogenitása, azaz a növénytípusok változatossága is negatívan befolyásolja. Korábbi kutatások vizsgálták a termesztett növények heterogenitása és a pacsirta egyedszáma közötti kapcsolatot; Angliában Chamberlain et al. (1999) szerint a pacsirta egyedszám sűrűsége az élőhely heterogenitásával együtt nő – a közép-angliai mezőgazdasági parcellákon azonban az élőhely heterogenitásának növekedésével csökkent a pacsirta egyedszám sűrűsége. Eredményeim alapján arra következtettem, hogy a termőhely típusa fontosabb tényező a pacsirta populáció egyedszáma szempontjából, mint a termőhely heterogenitásának mértéke. Blaschke et al. (2013) szerint az energianövények termesztésének növekedése az energiatájakon belül csökkenteni fogja a hagyományos mezőgazdaság és a természetvédelem alá vont területeket. A marginális hatások értékelése alapján sikerült azonosítanom azokat a terménytípusokat, amelyek pozitív (burgonya és cukorrépa) vagy negatív (silókukorica, állandó növényi kultúrák és repce) hatással voltak e madárfaj egyedszámára. Emellett a GLM-modellekben az egyes mezőgazdasági terményeket, mint változókat, a mezei pacsirta előfordulását befolyásoló hatásuk alapján rangsoroltam. Megállapítottam, hogy az energianövények (silókukorica) bevezetése és az energiatájak felszínborításának homogenizálódási folyamata negatív hatással van az mezei pacsirta populációjára.

A magyarországi mintaterületemen a felszínborítás/területhasználat és a pacsirta előfordulási adatai közötti kapcsolatot a regionális léptékű felszínborítás-adatbázis (CLC) mellett részletesebb, nagy méretarányú, Nemzeti Ökoszisztéma Alaptérkép (HEB) adatbázis alapján is vizsgálhattam. A HEB adatbázis egyedülálló lehetőséget kínált arra, hogy egy részletes felszínborítás-adatállományt használhassak országos léptékű elemzéshez, és összehasonlítsam egymással a különböző felszínborítás-adatbázisok alapján kapott élőhely-modellezés eredményeit. Ezt a nagy felbontású (20 X 20 m) adatbázist felhasználva azonosítottam a pacsirta által kedvelt és nem kedvelt felszínborítás-kategóriákat is, ezzel vizsgálva a felszínborítás-adatbázisok, a Corine Land Cover és a HEB alapján kapott eredmények méretarány-érzékenységét. Eredményeim szerint a pacsirta által nem kedvelt típusok negatív szignifikáns kapcsolatot mutatnak a pacsirta egyedszámával. Ezek a beépített és zöld városi területek, amelyek magas arányban beépített területekből állnak. Eredményeimet más nemzetközi publikációk is megerősítik (Gottschalk et al., 2010; Guerrero et al., 2012). A pacsirta előfordulási adatai negatív szignifikáns kapcsolatot mutattak a komplex művelési ág felszínborítás-típussal is. Más szerzők szerint a pacsirta nem kedveli a heterogén mezőgazdasági területeket, mert azok sokféle felszínborítás-típust tartalmaznak, mint például a szőlőültetvények, gyümölcs– és bogyósgyümölcs-ültetvények (növény magasság és sűrű növénytakaró kedvezőtlen) (Berg et al., 2015; Redlich et al., 2018).

Eredményeim szerint a pacsirta által nem kedvelt felszínborítás-típusok az előzőekben említetteken túl az erdők és vízfelszínek. A HEB-adatbázisban sok erdőtípus található, de ezeket összevontan kezeltem, mivel más tanulmányok szerint az erdőterületek bármely típusa nem élőhelye ennek a fajnak.

A nemzetközi szakirodalom szerint ennek az agrártájakat kedvelő madárfajnak jól ismert élőhelytípusai a szántóföldek (Dietzen et al., 2014; Hoffmann et al., 2018, 2016; Praus és Weidinger, 2015). A gyep– és legelőterületek szintén kedvelt kategóriák a mezei pacsirta számára (Hamer et al., 2006; Koleček et al., 2015; Moreira et al., 2005; Piha et al., 2003; Reif és Hanzelka, 2016). Eredményeim szerint a szikes gyepek és rétek, valamint a zárt gyepek kategóriái szignifikáns pozitív kapcsolatot mutatnak a pacsirta előfordulási adataival. A növényzet közepes magassága és a növényzet sűrűsége miatt e kategóriák alkalmas élőhelyek a pacsirták számára. A pacsirta által kedvelt felszínborítás-típusok tájmintázat-mutatói pozitív szignifikáns kapcsolatban állnak a pacsirta egyedszámával, ami azt jelenti, hogy ha a szántóföldek és gyepek aránya magasabb és foltjainak alakja összetettebb, akkor a pacsirta populációja is növekedik. A pacsirta egyedszám sűrűsége negatív szignifikáns kapcsolatban áll a nem preferált felszínborítás-típusok tájmintázat-mutatóival, ami arra utal, hogy e faj egyedsűrűsége alacsonyabb a kisebb méretű és kompakt formájú nemkedvelt felszínborítás-típusok foltjaiból összeálló tájakon. Meg tudtam erősíteni más szerzők eredményeit, miszerint a pacsirta a nagy szántóföldeket (parcellákat) és gyepterületeket részesíti előnyben a kis szántóföldekkel (parcellákkal) és gyepterületekkel szemben az 1:100000 méretarányú CLC felszínborítás-adatbázis alapján (Donald et al., 2001; Hamer et al., 2006; Moreira et al., 2005; Perkins et al., 2000).

Megállapításaim szerint az EU agrár-környezetvédelmi politikájának nagyobb figyelmet kellene fordítania a szikes gyepek és rétek, valamint a zárt gyepterületek kezelésére az agrártájakat kedvelő madarak élőhelyének konzerválásához. A mezei pacsirta egyedszámának növelése érdekében mind a szántók és gyepek átlagos méretét, mind pedig e felszínborítás típusok arányát a tájban (az összeshez képest) növelni kellene. A védett gyepterületek egyik legsúlyosabb ökológiai problémája a bokros lágyszárú növényzet spontán terjedése, amely veszélyezteti a pacsirta élőhelyét. Az ilyen gyepterületeken belül csökkenteni kellene a bokros lágyszárú és erdőfoltok méretét és alakját. Ehhez megfelelő legeltetési vagy kaszálási technikákat kell alkalmaznunk a spontán terjedő bokros növényzet (amely gyakran tele van inváziós fajokkal) kiirtására. Ez a fajta területkezelés nemcsak a gyepek növényzetének sokszínűségét segít megőrizni, hanem a pacsirta élőhelyének védelmét is elősegíti. Uuemaa et al. 2009 szerint a legtöbb madárfaj érzékenyebb a felszínborítás összetételére, mint a táj strukturáltságára (felszínborítás foltjainak méretére és alaki mutatóira) (8.3. ábra). Eredményeim szerint a tájmintázat-mutatók alkalmazása a modellben növelte a pacsirtaegyedszám becslésének pontosságát, az átlagos százalékos hibaérték 46,56%-ról 37,77%-ra csökkent. A becsült állománysűrűség-értékek (0-6,13 egyed/km^2) illeszkednek a nemzetközi publikációk eredményeihez (1,72-7,45 egyed/km^2) (Browne et al., 2000; Copland et al., 2012; Eraud és Marie Boutin, 2002; Suárez et al., 2003).



Ábra 8.3. A mezei pacsirta élőhelyének ideális táj kompozíciója és konfigurációja

Mivel a pacsirta a táj strukturális jellemzőire érzékeny faj és egyben a mezőgazdasági területek madárfaunájának egyik jellemző indikátorfaja, az itt alkalmazott módszertan hasznos lehet más mezőgazdasági tájakat kedvelő fajok populációjának változáselemzéséhez és egyedszám becsléséhez. Mivel előfordulása szoros kapcsolatot mutat más szántóföldi madárfajokkal, a pacsirta a mezőgazdasági tájak madárfaunájának indikátorfajának tekinthető (Gippoliti és Battisti, 2017).

Két európai területen vizsgáltam a felszínborítás-típusok és a pacsirta egyedszámai közötti összefüggéseket. A GLM-alapú modell alapján, a magyarországi mintaterületeken a pacsirta egyedszáma és felszínborítás-típusok között kapcsolat mutatható ki, ami nyolc típus esetében mutat szignifikáns statisztikai összefüggést. Schleswig-Holsteinben a pacsirtaállomány-adatok hat LULC-kategóriával mutatnak szignifikáns kapcsolatot.

A magyar mintaterületen a természetes gyepterületek pozitív statisztikai kapcsolatot mutatnak a pacsirta egyedszámával. Ahogy korábban említettem, ez a felszínborítástípus fontos élőhely az agrártájakat kedvelő madarak számára (Morelli, 2013). A szántóföldek művelésének felhagyása a parlag, illetve gyepterületek növekedését eredményezte Közép– és Kelet-Európában. Ezek fontos élőhelyet jelentenek a pacsirta számára, ha nem válnak lágyszárú bozótos vagy cserjés területté (Tryjanowski et al. 2011). Elemzéseim során nem találtam szignifikáns kapcsolatot a pacsirta egyedszáma és a legelők felszínborítási kategóriái között, mivel az intenzív gyepgazdálkodási gyakorlat Magyarországon káros lehet a fészkelő madár számára. Heldbjerg et al. (2018) szerint Dániában a legeltetésről kaszálásra való áttérés a pacsirták egyedszámában jelentős csökkenést eredményezett. A német mintaterületre vonatkozó eredményeim alapján a pacsirta egyik legjellemzőbb élőhelye a legelő, mivel a legeltetés alacsony növényzetet és homogén szerkezetet tart fenn (a mérsékelt legeltetés nem zavarja a mezei pacsirtát) (Cramp, 1988; Hoffmann et al. 2016; Koleček et al., 2015). Az általam választott két európai mintaterületen e tekintetben eltérő eredményeket kaptam. A különbségek Tryjanowski et al. (2011) szerint a mintaterületek eltérő, Nyugat– és Közép-Európai földrajzi helyzetének tudhatók be. Nyugat– és Közép-Európa között a mezőgazdasági művelés intenzitása kapcsán nagyok a különbségek. Magyarországon a mezőgazdaság vegyes rendszerű, ahol az intenzív és a hagyományos gazdálkodás egymás mellett létezik (Báldi és Faragó, 2007). Schleswig-Holsteinben a mezőgazdasági parcellák mérete régiónként eltérő, a tartomány keleti területei intenzíven művelt mezőgazdasági terület, nagy parcellákkal. A tartomány középső területein hagyományosan az állattenyésztés számára szánt rétek és legelők a jellemzőek, míg a nyugati területeken közepes és nagyméretű szántóföldek vagy gyepterületek találhatók.

Összehasonlítottam a pacsirta élőhelyében és egyedszámában országos szinten bekövetkezett változásokat, és a pacsirta által kedvelt és nem kedvelt felszínborítás-kategóriák változása alapján térképeztem a pacsirta élőhelyében bekövetkezett együttes változásokat európai léptékben. Az európai élőhelyváltozások jellemzőit olyan térképen szemléltettem, mely a pacsirta élőhelyében kontinentális léptékben bekövetkezett legjelentősebb változásokat mutatja. Az Egyesült Királyság, Írország, Németország, Dánia, Magyarország, Szlovákia és Spanyolország az ilyen hotspot területek közé tartoznak, ahol nagyobb területeken történt negatív irányú felszínborítás változás e madárfaj élőhelyében. Észak-Németországban (Schleswig-Holstein és Hessen) például egyértelműen olyan felszínborítás-változások történtek, amelyek negatívan hatnak a pacsirtaállomány egyedszámára (Csikós és Szilassi, 2020; Lüker-Jans et al. 2017). Heldbjerg et al. szerint Dániában a mezei pacsirta populációja csökkent az új agrár-környezetgazdálkodási rendszerek (AES, 2001-2014) következtében, amelyek a felszínborítás változását eredményezték (Heldbjerg et al., 2018). Daskalova et al. (2019) ugyanerről a jelenségről számol be Skóciában, azt állítva, hogy az új AES következtében csökkent a mezőgazdasági területek madárpopulációja. Magyarországon a gyepek és rétek újra erdősítése miatt szintén csökkenő tendencia figyelhető meg az egyedszám tekintetében (Szilassi et al. 2019). A pacsirta populációja jelentős statisztikai összefüggéseket mutatott a közelmúltbeli élőhelyváltozásokkal, ez az eredmény megerősíti saját eredményeimet. A bemeneti adatokhoz más paraméterek (tájindexek) hozzáadása egyértelműen javította a modell pontosságát a mezei pacsirta közelmúltbeli egyedszám-változásainak előrejelzése során.

Dolgozatom eredményeit összegezve megállapíthatom, hogy a felszínborítás és tájszerkezet változásai erősen befolyásolják a mezőgazdasági tájak állatvilágát, különösen a madárvilágot. Nyugat– és Közép-Kelet-Európában különböző mozgatórugói vannak a felszínborítás-változásnak. Európában azok a felszínborítás változások a dominánsak, amelyek a pacsirtapopuláció csökkenését eredményezték. Eredményeim szerint a két vizsgált mintaterületen belül, Magyarország és Schleswig-Holstein alapján kvantitatív módon meg tudtam becsülni a pacsirta élőhelyváltozásait.

Magyarországi eredményeim szerint az elmúlt két évtizedben a mezőgazdasági területek művelés alóli kivonása és az erdősítés volt a fő mozgatórugója a területborítás változásának. A legelők és állandó növényi kultúrák aránya az összes vizsgált tájablakon belül (pufferzónák) szignifikáns pozitív statisztikai összefüggést mutattak a mezei pacsirta gyakorisági és egyedsűrűség adataival regionális léptékű felszínborítás adatbázis alapján (CLC adatbázis). A városi beépített területek és a heterogén mezőgazdasági területek felszínborítás kategóriák az eredményeim szerint nem pufferzónaméret-függő változók, ami azt jelenti, hogy ezek a felszínborítás-típusok minden vizsgált tájablakban (300 m, 600 m, 1200 m sugarú pufferzónákon belül) negatív szignifikáns kapcsolatot mutatnak a pacsirta előfordulási adataival. Előrejelzéseim szerint a mezei pacsirta élőhelyvesztése legalább 2050-ig folytatódni fog.

Schleswig-Holstein szövetségi államban az energiatájak által generált felszínborítás-változás a mezőgazdasági madárfauna populációjának csökkenését okozza. A biogázerőművek telepítésével (energianövények termesztése) megváltozik a korábbi legelőterületek foltjainak mérete és alakja, miközben növekszik a szántóföldi felszínborítás foltok területe, mérete és összetettsége. Ezen a mintaterületen a nagy, homogén energianövény-parcellák erősen csökkentették a táj felszínborításának heterogenitását.

Kimutattam, hogy a felszínborítás és a termesztett növények diverzitása negatív hatással van a mezei pacsirta populációjára, azonosítottam olyan mezőgazdasági terményeket, amelyek területi jellemzői pozitív (burgonya és cukorrépa) vagy negatív (silókukorica, állandó kultúrák és repce) hatással voltak e madárfaj egyedszámára. Megállapíthatom, hogy az energianövények (silókukorica, repce) termesztésének bevezetése, valamint az energiatájak felszínborításának homogénebbé válása negatív hatással vannak az mezei pacsirta populáció egyedszámára.

Eredményeim szerint a pacsirta egyedszáma és annak változása mindkét mintaterületen belül szoros összefüggésben van a tájszerkezettel (felszínborítás-kategóriák arányaival, alaki és területi jellemzőivel). Kimutattam, hogy Magyarországon a szikes gyepek és rétek, valamint a zárt gyepek szolgálnak élőhelyül a mezei pacsirta számára. Statisztikai elemzésem szerint a gyepfoltok alaki összetettségét leíró fraktáldimenzió-index pozitív kapcsolatot mutatott a pacsirta egyedszámával, míg a nem élőhelytípusok alaki összetettsége ellentétes összefüggést mutat Magyarországon. Eredményeim szerint a mezei pacsirta egyedszám-sűrűsége alacsony hibaértékkel becsülhető a Magyarországi Natura 2000 területeken belül. Magyarországi eredményeim alapján elmondható, hogy a védett területeken növelni kell a szántóföldek, a szikes gyepek és rétek, valamint a zárt gyepek arányát, átlagos méretét és alaki összetettségét, hogy megőrizzék az agrárterületeket kedvelő fajok, köztük a pacsirta élőhelyét.

Dolgozatomban a különböző társadalmi-gazdasági tényezők vezérelte tájváltozások hatását vizsgáltam az agrárfauna populációjára. A mezei pacsirta felszínborítás alapján történő egyedszámbecslésének méretarány-érzékenységét vizsgáltam különböző méretarányú felszínborítás adatbázisok felhasználásával. Eredményeim fontosak lehetnek az agrártájakat kedvelő madárfajok egyedszám és élőhelyváltozás becsléséhez, olyan területeken, ahol nem állnak rendelkezésre részletes madármegfigyelési adatok. A dolgozat eredményei tájtervezési, természetvédelmi kezelési szempontból is jelentősek lehetnek, mert a védett természeti területeken olyan új tájszerkezet tervezéséhez szolgálhatnak adalékul, mely a jelenleginél kedvezőbb élőhelyet teremthet az agrártájak madarainak, különösen a mezei pacsirtának.

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Appendix

Appendix 2.1. The CLC nomenclature, and the CLC categories, which exist in Hungary. The grey coloured CLC categories show the most common CLC categories surroundings of the Skylark observation points, which were used for the statistical analyses (Source: EEA and ETC-TE, 2017).

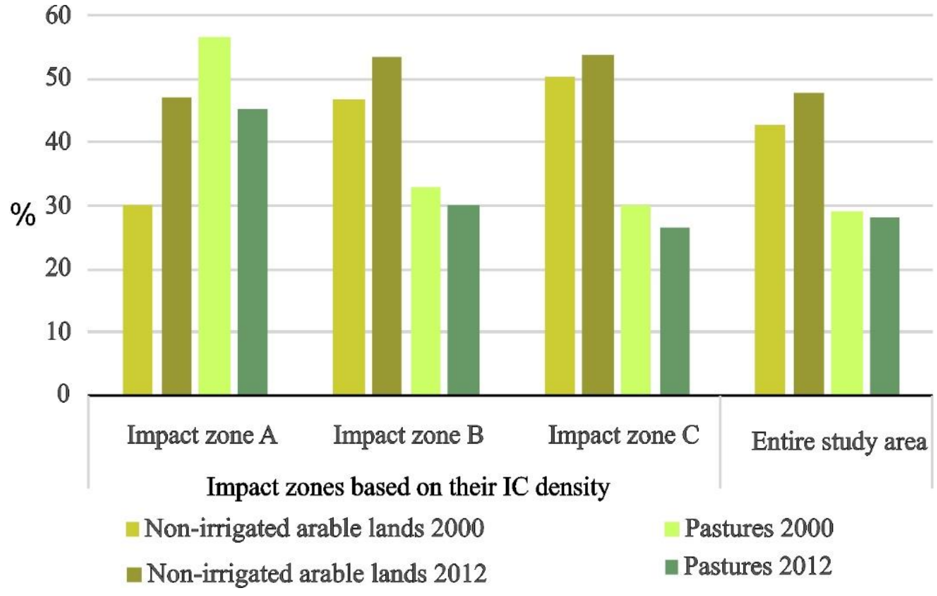
CLC categories		
1 level	2 level	3 level
1 Artificial surfaces	11 Urban fabric area	111 Continuous urban fabric
		112 Discontinuous urban fabric
	12 Industrial, commercial and transport units	121 Industrial or commercial units
		122 Road and rail networks and associated land
		123 Port areas
		124 Airports
	13 Mine, dump and construction sites	131 Mineral extraction sites
		132 Dump sites
		133 Construction sites
	14 Artificial, non-agricultural vegetated areas	141 Green urban areas
		142 Sport and leisure facilities
2 Agricultural areas	21 Arable land	211 Non-irrigated arable land
		213 Rice fields
	22 Permanent crops	221 Vineyards
		222 Fruit trees and berry plantations
	23 Pastures	231 Pastures
	24 Heterogeneous agricultural areas	242 Complex cultivation patterns
		243 Land principally occupied by agriculture, with significant areas of natural vegetation
3 Forest and semi natural areas	31 Forests	311 Broad-leaved forest
		312 Coniferous forest
		313 Mixed forest
	32 Scrub and/or herbaceous vegetation associations	321 Natural grasslands
		324 Transitional woodland-shrub
	33 Open spaces with little or no vegetation	333 Sparsely vegetated areas
4 Wetlands 5 Water bodies	41 Inland wetlands	411 Inland marshes
		412 Peat bogs
	51 Inland waters	511 Water courses
		512 Water bodies

Appendix 2.2. Detailed description of the 'Skylark preferred' CLC categories based on the CLC nomenclature (EEA and ETC-TE, 2017).

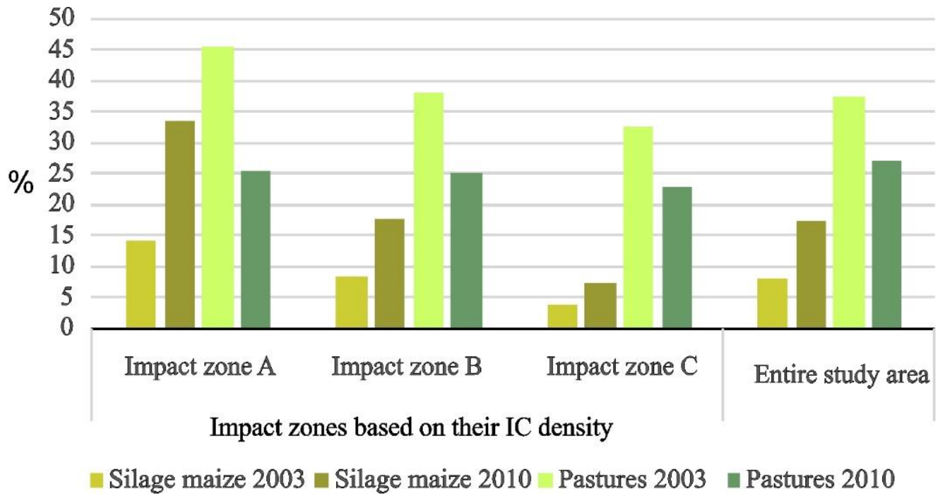
CLC code	Name of the CLC category	Description
14	Artificial, non-agricultural vegetated areas	Areas voluntarily created for recreational use. Includes green or recreational and lei-sure urban parks. sport and leisure facilities.
23	Pastures	Lands that are permanently used (at least 5 years) for fodder production. Includes natural or sown herbaceous species, unimproved or lightly improved meadows and grazed or mechanically harvested meadows. Regular agriculture impact influences the natural development of natural herbaceous species composition.
22	Permanent crops	All surfaces occupied by permanent crops not under a rotation system. Includes ligneous crops of standards cultures for fruit production such as extensive fruit orchards. Olive groves, chestnut groves, walnut groves shrub orchards such as vineyards and some specific low-system orchard plantation.

Appendix 2.3. Detailed description of the 'Skylark not preferred' CLC categories based on the CLC nomenclature (EEA and ETC-TE, 2017)

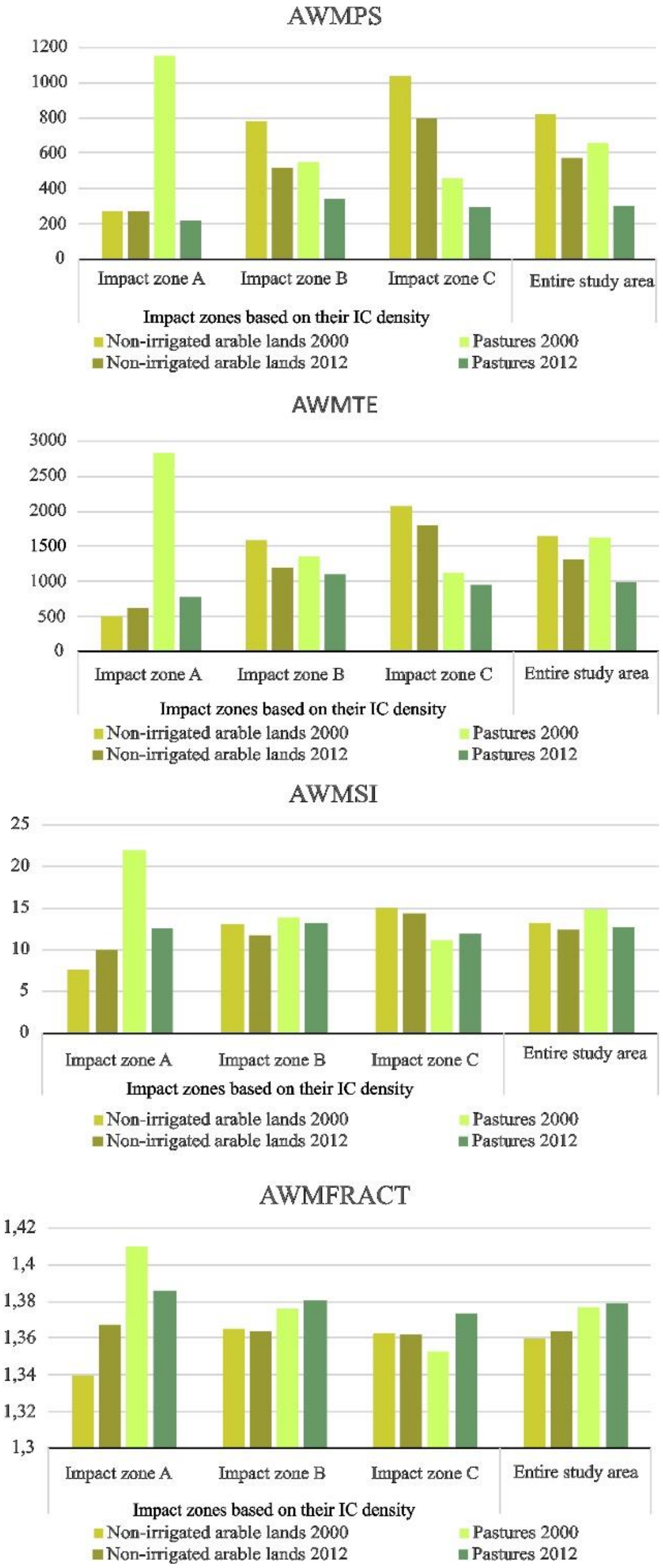
CLC code	Name of the CLC category	Description
11	Urban fabric area	Areas mainly occupied by dwellings and buildings used by administrative/public utilities. including their connected areas (associated lands. approach road network. parking lots).
24	Heterogeneous agricultural areas	Areas of annual crops associated with permanent crops on the same parcel. annual crops cultivated under forest trees. areas of annual crops. meadows and/or permanent crops which are juxtaposed. landscapes in which crops and pastures are intimately mixed with natural vegetation or natural areas.
31	Forests	Areas occupied by forests and woodlands with a vegetation pattern composed of native or exotic coniferous and/or broad-leaved trees and which can be used for the production of timber or other forest products. The forest trees are under normal climatic conditions higher than 5 m with a canopy closure of 30 % at least.
32	Scrub and/or herbaceous vegetation associations	Grasslands under no or moderate human influence. Low productivity grasslands. Often situated in areas of rough. uneven ground, steep slopes. Vegetation with low and closed cover. dominated by bushes, shrubs, dwarf shrubs and herbaceous plants. forming a climax stage of development. Transitional bushy and herbaceous vegetation with occasional scattered trees. Can represent woodland degradation. forest regeneration, recolonization or natural succession.
41 and 51	Inland wetlands and Inland water bodies	Areas flooded or liable to flooding during the great part of the year by fresh, brackish or standing water with specific vegetation coverage made of low shrub. Semi-ligneous or herbaceous species. Includes water fringe vegetation of lakes, rivers, and brooks Highly oligotrophic and strongly acidic communities composed mainly of sphagnum growing on peat and deriving moistures of raised bogs and blanket bogs. Lakes, ponds and pools of natural origin containing fresh water and running waters made of all rivers and streams. Man-made fresh water bodies including reservoirs and canals.



Appendix 3.1. Proportion of the non-irrigated arable lands and pastures at utilized land area in the entire study area and in the Installed electrical Capacity (IC) density-based impact zones, based on CLC 2000 and 2012 database.



Appendix 3.2. Percentage of pasture and silage maize areas in the entire study area and in the Installed electrical Capacity (IC) density-based impact zones, based on ASE 2003 and 2010 database.



Appendix 3.3. Size and shape related class level landscape metrics of non-irrigated arable lands and pastures, based on CLC 2000 and CLC 2012 databases (IC = Installed electrical Capacity, AWMPS = Area weighted mean patch size, AWMTE = Area weighted mean total edge, AWMSI = Area weighted mean shape index, AWMFRACT = Area weighted mean fractal dimension index).

Appendix 3.4. Description of area, edge, shape and diversity metrics used in this study (based on (Blaschke, 2006; Forman, 1995; Fu et al., 2006; Moser et al., 2002; Renetzeder et al., 2010; Turner, 1990; Uuemaa et al., 2013; Walz, 2011)*).*

Investigated feature	**Database used for calculation**	**Index**	**Name and description**	**Corresponding question**
Area	CLC	MPS	Mean Patch Size $MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}$ where aij represents the area of the jth patch in the ith class, ni represents the number of patches in the ith class, n represents the number of patches (>0)	What is the average land cover patch size, and how are the values distributed?
Edges	CLC	TE	Total Edge $TE = \sum_{k=1}^{m} e_{ik}$ where eik represents the edge length between the ith and kth patch types, m represents the number of the patch class (<=0).	How much of a landscape or a land cover patch type is composed of edges?
Shape complexity	CLC	MSI	Mean Shape Index $MSI = \frac{\sum_{j=1}^{n} \left(\frac{p_{ij}}{\sqrt[2]{\pi * a_{ij}}} \right)}{n_i}$ where pij represents the perimeter of the jth patch in class ith, aij represents the area of the jth patch in class ith, ni represents the number of patches in the ith class, n represents the number of patches (>=1)	How compact are the patches on average (in comparison to a circle)?
	CLC	MFRACT	Mean Fractal Dimension $MFRACT = \frac{\sum_{j=1}^{n} \left(\frac{2 \ln p_{ij}}{\ln a_{ij}} \right)}{n_i}$ where pij represents the perimeter of the jth patch in class ith, aij represents the area of the jth patch in class ith, ni represents the number of patches in the ith class, n represents the number of patches (1–2)	How complex or irregular is the form of the land cover patch?
Diversity metrics	CLC and ASE	SDI	Shannon Diversity Index $SDI = -\sum_{i}^{m} (P_i * \ln(P_i))$ Where (m) represents the number of different land cover types, Pi = the relative abundance of different land cover types	How diverse is the landscape?
	CLC and ASE	SEI	Shannon Evenness Index $SEI = \sum_{i}^{m} \frac{(P_i * \ln(P_i))}{\ln(m)}$ SEI covers the number of different land cover types (m) and their relative abundance (P_i)	How equal is the distribution of the land cover patches in the landscape?
	CLC and ASE	RI	Richness Index presents simply the variety or number of patch types in landscape level.	How many different land cover patch types build the landscape?

Appendix 3.5. Land cover diversity indices between 2000 and 2012, based on CLC database (IC = Installed electrical Capacity).

Year	Landscape diversity indices	Impact zones based on their IC density			Total study area
		Impact zone A	Impact zone B	Impact zone C	
2000	Richness	20	32	32	32
	Shannon Diversity	1.207	1.506	1.523	1.757
	Shannon Evenness	0.403	0.435	0.44	0.507
2012	Richness	20	31	31	33
	Shannon Diversity	1.067	1.354	1.464	1.597
	Shannon Evenness	0.356	0.394	0.419	0.457

Appendix 3.6. One-way ANOVA of landscape indices of non-irrigated arable lands in the three impact zone.

		Sum of Squares	df	Mean Square	F	Sig.
AWMPS	Between Groups	2.26×10^{19}	2	1.13×10^{19}	27	3.578×10^{-12}
	Within Groups	4.54×10^{20}	1087	4.18×10^{17}		
	Total	4.77×10^{20}	1089			
AWMTE	Between Groups	1.11×10^{14}	2	5.56×10^{13}	25.612	1.352×10^{-11}
	Within Groups	2.36×10^{15}	1087	2.17×10^{12}		
	Total	2.47×10^{15}	1089			
AWMSI	Between Groups	1.62×10^{3}	2	811.289	10.891	2.074×10^{-5}
	Within Groups	8.10×10^{4}	1087	74.491		
	Total	8.26×10^{4}	1089			
AWMFRACT	Between Groups	2.56×10^{-3}	2	0.001	0.515	0.598
	Within Groups	2.681	1078	0.002		
	Total	2.684	1080			

Appendix 3.7. Tukey post hoc test of landscape indices of non-irrigated arable lands in the three impact zone.

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.
AWMPS	Impact zone A	Impact zone B	-1.665×10^{8}	5.84×10^{7}	1.226×10^{-2}
		Impact zone C	-4.047×10^{8}	6.08×10^{7}	5.223×10^{-9}
	Impact zone B	Impact zone A	1.665×10^{8}	5.84×10^{7}	1.226×10^{-2}
		Impact zone C	-2.382×10^{8}	4.29×10^{7}	1.103×10^{-7}
	Impact zone C	Impact zone A	4.047×10^{8}	6.08×10^{7}	5.223×10^{-9}
		Impact zone B	2.382×10^{8}	4.29×10^{7}	1.103×10^{-7}
AWMTE	Impact zone A	Impact zone B	-3.833×10^{5}	1.33×10^{5}	1.123×10^{-2}
		Impact zone C	-9.048×10^{5}	1.38×10^{5}	5.384×10^{-9}
	Impact zone B	Impact zone A	3.833×10^{5}	1.33×10^{5}	1.123×10^{-2}
		Impact zone C	-5.215×10^{5}	9.78×10^{4}	3.550×10^{-7}
	Impact zone C	Impact zone A	9.048×10^{5}	1.38×10^{5}	5.384×10^{-9}
		Impact zone B	5.215×10^{5}	9.78×10^{4}	3.550×10^{-7}
AWMSI	Impact zone A	Impact zone B	−1.029	7.79×10^{-1}	0.384
		Impact zone C	−3.231	8.11×10^{-1}	2.140×10^{-4}
	Impact zone B	Impact zone A	1.029	7.79×10^{-1}	0.384
		Impact zone C	−2.203	5.73×10^{-1}	3.737×10^{-4}
	Impact zone C	Impact zone A	3.231	8.11×10^{-1}	2.140×10^{-4}
		Impact zone B	2.203	5.73×10^{-1}	3.737×10^{-4}
AWMFRACT	Impact zone A	Impact zone B	0.004	4.51×10^{-3}	0.590
		Impact zone C	0.004	4.69×10^{-3}	0.637
	Impact zone B	Impact zone A	−0.004	4.51×10^{-3}	0.590
		Impact zone C	0.000	3.32×10^{-3}	0.998
	Impact zone C	Impact zone A	−0.004	4.69×10^{-3}	0.637
		Impact zone B	0.000	3.32×10^{-3}	0.998

Appendix 3.8. One-way ANOVA of landscape indices of pastures in the three impact zone.

		Sum of Squares	df	Mean Square	F	Sig.
AWMPS	Between Groups	1.18×10^{18}	2	5.91×10^{17}	5.941	0.003
	Within Groups	1.08×10^{20}	1088	9.95×10^{16}		
	Total	1.09×10^{20}	1090			
AWMTE	Between Groups	1.08×10^{13}	2	5.41×10^{12}	5.658	0.004
	Within Groups	1.04×10^{15}	1088	9.56×10^{11}		
	Total	1.05×10^{15}	1090			
AWMSI	Between Groups	742.387	2	371.194	5.425	0.005
	Within Groups	74,438.765	1088	68.418		
	Total	75,181.153	1090			
AWMFRACT	Between Groups	0.027	2	0.014	4.714	0.009
	Within Groups	3.142	1088	0.003		
	Total	3.169	1090			

Appendix 3.9. Tukey post hoc test of landscape indices of pastures in the three impact zone.

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.
AWMPS	Impact zone A	Impact zone B	-6.27×10^{7}	2.84×10^{7}	0.071
		Impact zone C	4.37×10^{6}	2.96×10^{7}	0.988
	Impact zone B	Impact zone A	6.27×10^{7}	2.84×10^{7}	0.071
		Impact zone C	6.71×10^{7}	2.09×10^{7}	0.004
	Impact zone C	Impact zone A	-4.37×10^{6}	2.96×10^{7}	0.988
		Impact zone B	-6.71×10^{7}	2.09×10^{7}	0.004
AWMTE	Impact zone A	Impact zone B	-1.52×10^{5}	8.81×10^{4}	0.196
		Impact zone C	6.08×10^{4}	9.17×10^{4}	0.785
	Impact zone B	Impact zone A	1.52×10^{5}	8.81×10^{4}	0.196
		Impact zone C	2.13×10^{5}	6.49×10^{4}	0.003
	Impact zone C	Impact zone A	-6.08×10^{4}	9.17×10^{4}	0.785
		Impact zone B	-2.13×10^{5}	6.49×10^{4}	0.003
AWMSI	Impact zone A	Impact zone B	-7.17×10^{-2}	7.45×10^{-1}	0.995
		Impact zone C	1.66	7.75×10^{-1}	0.082
	Impact zone B	Impact zone A	7.17×10^{-2}	7.45×10^{-1}	0.995
		Impact zone C	1.73	5.49×10^{-1}	0.005
	Impact zone C	Impact zone A	−1.6	7.75×10^{-1}	0.082
		Impact zone B	−1.73	5.49×10^{-1}	0.005
AWMFRACT	Impact zone A	Impact zone B	3.05×10^{-3}	4.84×10^{-3}	0.803
		Impact zone C	1.25×10^{-2}	5.04×10^{-3}	0.035
	Impact zone B	Impact zone A	-3.05×10^{-3}	4.84×10^{-3}	0.803
		Impact zone C	9.48×10^{-3}	3.56×10^{-3}	0.022
	Impact zone C	Impact zone A	-1.25×10^{-2}	5.04×10^{-3}	0.035
		Impact zone B	-9.48×10^{-3}	3.56×10^{-3}	0.022

Appendix 3.10. One-way ANOVA of diversity indices in the three impact zone.

		Sum of Squares	df	Mean Square	F	Sig.
SDI	Between Groups	8.776	2	4.388	26.623	5.09×10^{-12}
	Within Groups	182.614	1108	0.165		
	Total	191.390	1110			
SEI	Between Groups	3.545	2	1.773	13.991	9.98×10^{-7}
	Within Groups	140.383	1108	0.127		
	Total	143.929	1110			
RI	Between Groups	76.733	2	38.366	20.631	1.60×10^{-9}
	Within Groups	2060.522	1108	1.860		
	Total	2137.255	1110			

Appendix 3.11. Tukey post hoc test of diversity indices in the three impact zone.

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.
SDI	Impact zone A	Impact zone B	−0.150040	0.036519	0.000126
		Impact zone C	−0.268	0.037869	0.000000
	Impact zone B	Impact zone A	0.150	0.036519	0.000126
		Impact zone C	−0.118	0.026599	0.000029
	Impact zone C	Impact zone A	0.268	0.037869	0.000000
		Impact zone B	0.118	0.026599	0.000029
SEI	Impact zone A	Impact zone B	−0.122	0.032019	0.000445
		Impact zone C	−0.176	0.033203	0.000000
	Impact zone B	Impact zone A	0.122	0.032019	0.000445
		Impact zone C	−0.054	0.023321	0.055313
	Impact zone C	Impact zone A	0.176	0.033203	0.000000
		Impact zone B	0.054	0.023321	0.055313
RI	Impact zone A	Impact zone B	−0.360	0.123	0.009628
		Impact zone C	−0.763	0.127	0.000000
	Impact zone B	Impact zone A	0.360	0.123	0.009628
		Impact zone C	−0.403	0.089	0.000021
	Impact zone C	Impact zone A	0.763	0.127	0.000000
		Impact zone B	0.403	0.089	0.000021

Appendix 4.1. CLC nomenclature and CLC categories, Source:(Bossard et al., 2000; Cole et al., 2018; Kosztra et al., 2019).

CLC (code)	Name of the CLC Category (Model)	Description
11	Urban fabric area	Areas mainly occupied by dwellings and buildings used by administrative/public utilities, including their connected areas (associated lands, approach road network, and parking lots).
12	Industrial, commercial, and transport units	Areas mainly occupied by industrial activities of manufacturing, trade, financial activities and services, transport infrastructures for road traffic and rail networks, airport installations, river and sea port installations, including their associated lands and access infrastructures. Includes industrial livestock rearing facilities.
14	Artificial, non-agricultural vegetated areas	Areas voluntarily created for recreational use. Includes green or recreational and leisure urban parks, and sport and leisure facilities.
22	Permanent crops	All surfaces occupied by permanent crops not under a rotation system. Includes ligneous crops of standard cultures for fruit production, such as extensive fruit orchards, olive groves, chestnut groves, walnut groves shrub orchards such as vineyards and some specific low-system orchard plantation.
23	Pastures	Lands that are permanently used (at least for 5 years) for fodder production. Includes natural or sown herbaceous species, unimproved or lightly improved meadows, and grazed or mechanically harvested meadows. Regular agriculture impact influences the natural development of natural herbaceous species composition.
24	Heterogeneous agricultural areas	Areas of annual crops associated with permanent crops on the same parcel. Annual crops cultivated under forest trees. Areas of annual crops. Meadows and/or permanent crops that are juxtaposed. Landscapes where crops and pastures are intimately mixed with natural vegetation or natural areas.
31	Forests	Areas occupied by forests and woodlands with a vegetation pattern composed of native or exotic coniferous and/or broad-leaved trees and which can be used for the production of timber or other forest products. The forest trees are under normal climatic conditions higher than 5 m with a canopy closure of at least 30%.
32	Shrub and/or herbaceous vegetation associations	Grasslands under no or moderate human influence. Low-productivity grasslands. Often situated in areas of rough, uneven ground, steep slopes. Vegetation with low and closed cover dominated by bushes, shrubs, dwarf shrubs, and herbaceous plants, forming a climax stage of development. Transitional bushy and herbaceous vegetation with occasional scattered trees. Can represent woodland degradation, forest regeneration, recolonization, or natural succession.
41	Inland wetlands	Areas flooded or liable to flooding during the great part of the year by fresh, brackish, or standing water with specific vegetation coverage made of low shrub. Semi-ligneous or herbaceous species. Includes water fringe vegetation of lakes, rivers, and brooks. Highly oligotrophic and strongly acidic communities composed mainly of sphagnum growing on peat and deriving moistures of raised bogs and blanket bogs.
42	Coastal wetlands	Areas submerged by high tides at some stage of the annual tidal cycle. Includes salt meadows, faces of saltmarsh grass meadows, transitional or not to other communities, vegetation occupying zones of varying salinity and humidity, sands and muds submerged for part of every tide devoid of vascular plants, active or recently abandoned salt-extraction evaporation basins.

Appendix 4.2. ASE database nomenclature, source: (Hessisches Statistisches Landesamt, 2016).

Crop Type	**Description**
Oat	Cereal for grain production including seed production.
Permanent crops	Tree and berry orchards, nuts, vineyards, tree nurseries and Christmas tree crops, and poplar plants outside the forest.
Pasture	Permanent pasture includes all grassland areas outside of crop rotation — without interruption by other cultures — are used and for fodder or litter production or for grazing are determined. Permanent grassland areas are accordingly meadows, mowing pastures, and pastures.
Potato	Root crops category, potato fields.
Rape	Oil seed category, winter rape, and suitable for feeding biogas power stations.
Silage maize	Green forage category, used for feeding biogas power stations or livestock.
Sugar beet	Root crops category, used for feeding biogas power stations or livestock.
Wheat	In the category of winter crops, used for feeding biogas power stations or livestock.

Appendix 5.1. The LULC categories of the Hungarian Ecosystem Basemap, and the investigated LULC categories

HEB LULC categories			The investigated LULC categories	
Level 1	Level 2 Code	Level 2 (~ EUNIS 2)	Level 2 Code	Level 2
Urban	11	Buildings	10	Built-up
	12	Roads and railways		
	13	Other paved or non-paved artificial areas		
	14	Green urban areas	14	Green urban areas
Croplands	21	Arable land	21	Arable land
	22	Permanent crops	22	Permanent crops
	23	Complex cultivation pattern	23	Complex cultivation pattern
Grasslands and other herbaceous vegetations	31	Open sand steppes	31	Open sand steppes
	32	Salt steppes and meadows	32	Salt steppes and meadows
	33	Open rocky grasslands	33	Open rocky grasslands
	34	Closed grasslands in hills and mountains or on cohesive soil	34	Closed grasslands in hills and mountains or on cohesive soil
	35	Other herbaceous vegetation	35	Other herbaceous vegetation
Forests and woodlands	41	Forests without excess water	40	Forest
	42	Natural riverine (gallery) forests		
	43	Other forests with excess water		
	44	Plantations		
	45	Non-wooded areas registered as forest, or areas under reforestation		
	46	Other ligneous vegetation, woodlands		
Wetlands	51	Herbaceous-dominated wetlands	50	Wetlands and water surfaces
	52	Woodland-dominated wetlands (uncertain translation)		
Rivers and lakes	61	Water bodies		
	62	Water courses		

Appendix 5.2. Summary table for landscape metrics and LULC categories, which shows the GLM results after multimodel averaging of best candidate models showing relative importance of each explanatory variable on Skylark abundance, estimated parameter values ± Standard deviation. MPS is Mean Patch Size and MFRACT is Mean Fractal dimension.

Predictors	Estimate	Standard deviation	Conf. Int (95%)	P-Value	Relative importance (%)
(Intercept)	-3.2352 ***	0.3579	-3.9005 – -2.5772	<0.001	
MPS of arable lands	1.2850 ***	0.3588	0.6528 – 1.9195	<0.001	100
MPS of Grasslands	0.9689 ***	0.2755	0.4145 – 1.5358	<0.001	100
MFRACT of arable lands	-0.1719	0.2928	-0.7136 – 0.3745	0.557	31
MFRACT of grasslands	0.6255 **	0.2409	0.1657 – 1.0845	0.009	100
Total area of arable lands	1.6482 ***	0.1916	1.2788 – 2.0202	<0.001	100
Total area of grasslands	2.4023 ***	0.2731	1.8781 – 2.9262	<0.001	100
Number of MMM observations (data pairs): 1897					

* p<0.05   ** p<0.01   *** p<0.001

Appendix 5.3. Summary table of component models from model averaging

Variables	**df**	**logLik**	**AICc**	**delta**	**weight**
1/2/4/6/7/8/9/10/11	11	-4658.47	9339.02	0	0.38
1/2/3/4/6/7/8/9/10/11	12	-4657.9	9339.91	0.89	0.24
1/2/4/5/6/7/8/9/10/11	12	-4658.14	9340.39	1.37	0.19
1/2/4/6/7/8/10/11	10	-4660.2	9340.48	1.46	0.18

Appendix 6.1 Distribution of grid cells and CLC categories in the study areas

CLC code	Hungary					Schleswig-Holstein				
	Grids[1]	Grids %[2]	CLC %[3]	Number of patches	Mean Patch Size	Grids[1]	Grids %[2]	CLC %[3]	Number of patches	Mean Patch Size
112	142	79.33	6.66	240	122	199	96.14	11.61	536	71
133	10	5.59	0.10	19	35	1	0.48	0.02	2	28
141	6	3.35	0.11	15	44	17	8.21	0.24	24	33
211	174	97.21	48.09	297	455	207	100.00	18.27	707	311
222	52	29.05	1.16	54	40	1	0.48	0.01	2	57
231	160	89.39	8.46	300	51	207	100.00	24.40	1053	104
242	113	63.13	2.55	237	52	3	1.45	0.10	5	38
311	146	81.56	11.30	301	101	179	86.47	12.40	584	67
312	27	15.08	0.50	35	32	111	53.62	4.34	224	115
313	41	22.91	0.88	62	40	95	45.89	2.82	178	41
321	56	31.28	8.33	33	160	42	20.29	1.56	38	40
411	44	24.58	0.85	40	34	13	6.28	0.46	10	36
512	50	27.93	1.08	43	67	91	43.96	3.12	125	88

[1]Number of grids that contain the CLC category; [2]percentage of grids that contain the CLC category; [3] percentages of the CLC category.

Appendix 6.2. Names and descriptions of Corine Land Cover categories, Source: Bossard et al., 2000; Kosztra et al., 2019

Code	Name	Description
112	Discontinuous urban fabric	The discontinuous urban fabric class is allocated when urban structures and transport networks associated with vegetated areas and bare surfaces are present and keep significant amounts of surface in a discontinuous spatial pattern. Impermeable features such as roads, buildings, and artificially surfaced areas range from 30% to 80% land coverage.
133	Construction sites	Lands under construction development, soil or bedrock excavations and earthworks. This class is assigned to areas where the landscape is distressed by human activities, changed or modified into artificial surfaces, being in a state of anthropogenic transition.
141	Green urban areas	Areas with vegetation within or partly conquered by urban fabric. This class is assigned to urban greenery, which usually has recreational or ornamental character and is usually available to the public.
211	Non-irrigated arable land	Cultivated land units under rain-fed agricultural use for annually harvested non-permanent crops, normally under a crop rotation system, including fallow lands within such crop rotation. Parcels with sporadic sprinkler irrigation with non-permanent devices to support dominant rain-fed cultivation are included.
222	Fruit trees and berry plantations	Cultivated lands planted with fruit trees and shrubs, intended for fruit production, including nuts. The planting pattern can be by single or mixed fruit, both in association with permanently grassy surfaces.
231	Pastures	Permanent grassland characterized by agricultural use or strong human interference. Floral composition dominated by graminaceae and affected by human activity. Typically used for grazing or mechanical harvesting of grass to meadows.
242	Complex cultivation patterns	Mosaic of small cultivated land fields with different cultivation types -annual crops, pasture and/or permanent crops-, eventually with scattered houses or gardens.
311	Broad-leaved forest	Vegetation formation formed principally of trees, including shrub and bush, where broad-leaved species predominate.
312	Coniferous forest	Vegetation formation formed principally of trees, including shrub and bush understorey, where coniferous species predominate.
313	Mixed forest	Vegetation formation composed principally of trees, including shrub and bush understorey, where neither broad-leaved nor coniferous species predominate.
321	Natural grassland	Grasslands under no or moderate human affect. Low-productivity grasslands. Often situated in areas of rough, uneven ground and steep slopes; frequently including rocky areas or patches of other (semi-)natural vegetation.
411	Inland marshes	Low-lying land usually flooded in winter, and with ground more or less saturated by fresh water all year round.
512	Water bodies	Natural or artificial water bodies with presence of standing water surface during most of the year.