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RELATIONSHIP BETWEEN BIRD FAUNA DIVERSITY AND LANDSCAPE METRICS IN AGRICULTURAL LANDSCAPE: AN ESTONIAN CASE STUDY

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Abstract. In the present article, the species diversity of farmland birds has been correlated with different landscape indexes. Research areas were located in three counties: Valga county, Jõgeva county and Lääne-Viru county. For each research area, 10 research squares were randomly chosen (4 counting points were located in each square). In 2002 and 2004 two point counts were carried out in each test square. For gathering landscape data, vector-shaped Estonian Basic Map was used which was re-classified according to the ecologic importance on the birds of agricultural landscape. Vector data were rastered and after that landscape indexes were calculated: Patch Density, Edge Density and Shannon's Landscape Diversity Index. According to all the landscape indexes the most heterogeneous were the landscape squares in Valga county whereas average heterogeneity was found in Jõgeva county and the landscape of Lääne-Viru county was found to be the most homogenous. It appeared that there is a connection between the diversity of bird fauna of Estonian agricultural landscape and landscape structure (expressed through landscape indexes). In almost all studied cases it appeared that there was a stronger correlation between the landscape indexes calculated for larger area and bird variables. The correlation coefficients were the lowest in counting points with 100-meter buffer zone and the highest in 1 km² research squares. The result indicates that a too small area around the counting point may not give adequate information about landscape structure essential for birds. The research confirms earlier results that bigger fragmentation of patches may increase the local bird species diversity.

Introduction

The intensification of agriculture in Europe began after World War II (Pain & Pienkowski 1997; Siriwardena *et al.* 2000) and most likely it was the reason for the decrease in the number of agricultural landscape birds since the 1970s until the present day (Donald *et al.* 2006). Many researches have shown that modern agriculture is one of the main dangers for biological diversity and its effect is comparable to extensive climate changes (Donald *et al.* 2002; Donald *et al.* 2006; Wretenberg *et al.* 2006). In the 20th century, decrease of the bird populations of agricultural landscapes in Western and Northern Europe was connected with extensive changes in the use of land and change of the landscape structure (Fuller *et al.* 1995; Chamberlain & Fuller 2000; Virkkala *et al.* 2004). Extensive homogenous agricultural areas have been created (Söderström & Pärt 2000) which currently cover nearly half (45%) of Europe (Schifferli *et al.* 1999; Donald *et al.* 2002; Donald *et al.* 2006).

In Estonia, relatively little attention has been turned so far to the birds of agricultural landscapes. The following birds of arable land have been paid slightly more attention in the framework of the annual bird project of Estonian Ornithological Society: Corncrake (*Crex crex*; in 1995; Elts 1997), Eurasian Curlew (*Numenius arquata*; in 1996), Lapwing (*Vanellus vanellus*; in 2001), White Stork (*Ciconia ciconia*; in 2004) and Yellow Wagtail (*Motacilla flava*; in 2006). In addition, the number of breeding Lapwings and Eurasian Curlews has been described in Saue observation point within 40 years (Tuule *et al.* 2002; Tuule *et al.* 2003). From 2001–2003, a study was implemented which investigated the connections between the intensity of agriculture and the condition of the bird populations of agricultural landscapes in the Baltic States (Herzon 2007).

In 2005, Agricultural Research Centre started a bird observation project of agricultural landscapes in the framework of evaluating the biological diversity of agricultural environmental support of the Estonian Rural Development Plan 2004–2006 which extends up to the present day. Research areas are located in Võru county, Jõgeva/Tartu county and Saare county (22 observation farms in every county). The preliminary results have been concluded by Jaanus Elts (Elts 2006; Elts 2007).

Birds are extremely good indicators for studying the structure and composition of habitat (Burel *et al.* 1998). In the landscape-ecologic studies handling the bird fauna, the connection of a single species as well as species diversity and division thereof with landscape structure is paid great attention to. All over the world, forest birds have been studied in connection with the fragmentation of forests (Stephens *et al.* 2003; Lampila *et al.* 2005; Thompson 2007). For instance, species with small territory are able to inhabit landscape in which the ratio of suitable habitat is small and several territories can be included in this small habitat spot. As habitat spots can be located far from each other, the birds cannot cross them and can be left in isolation. The fragmentation of habitats is especially a problem in case of those species whose breeding territories are big. The fragmentation is often accompanied by nest predators, changes of microclimate and increase of the edge effect, which can create the increase of competition (Estades & Temple 1999; Brotons & Herrando 2001).

It must also be stressed that not all researchers have reached similar results as different computer programmes, methods, research areas have been used and the duration of studies has varied. For instance, Atauri & de Lucio (2001) found that the heterogeneity of landscape structure is the most important component for birds (compared to amphibians, reptiles and butterflies). The prevailing type of land use is just in the second place. Heikkinen *et al.* (2004) found upon the comparison of bird species diversity and landscape (leaving out the habitat) that the results must be handled with caution. The authors stress that upon the connection of species diversity and landscape structure, the ecologic importance of habitats should be primarily proceeded from upon the analysis of habitats. Nevertheless, several studies have been dedicated just to habitats and the structure of landscape has been disregarded (Burel *et al.* 1998). Generally, it can be said that diverse habitat pattern (Dramstad *et al.* 2001; Benton *et al.* 2003) as well as the diversity of the surrounding landscape structure (Tryjanowski 1999) are important for the birds of agricultural landscapes as a whole.

The development of landscape ecology, modelling and geographical information systems during the past decades enables to investigate the connections between the number of birds, species diversity, use of land and structural elements of landscape nowadays in more detail. One possibility is to evaluate the structure of landscape and habitats with the help of landscape indexes and thereby to establish the effect of landscape structure on the diversity of bird fauna.

The objective of this article was to study the connections between the landscape indexes calculated for study areas with different sizes and the indicators of bird fauna diversity of agricultural landscape. Upon the calculation of landscape indexes, research units with different sizes were used, as it is unclear up to now how big should the radius be around the specific landscape structure of counting transect/study area. Depending on the objectives, the authors of different research works have calculated the landscape structure and sizes of the studied areas differently as a rule. What is more, details of the digital land use maps (in case of land use types) and the scales of the maps itself differ greatly. The Estonian basic map (1:10 000) has sufficient level of details as many objects with small areas (*e.g.* piles of stone, single trees *etc.*) have been pictured on it, which are extremely important breeding areas for many birds. Moreover, the basic map can be classified to be more specific if necessary (*e.g.* to distinguish different arable crops). That is why one of the objectives of the work is to establish the possibilities of use of the basic map landscape features upon the description of bird fauna.

The following hypothesis was established in the study: landscapes with a high patch density, edge density and landscape diversity have also higher species diversity and density.

Methods

C o n c e p t s. Research square: square with the size of 1 km². There are 10 squares in each studied county. Counting point: 4 counting points were located on each research square. Each county had 4 x 10 counting points *i.e*. 40 counting points (total of 120 in three counties).

R e s e a r c h a r e a s. Research areas (Fig. 1) were chosen by Irina Herzon from University of Helsinki in 2002 in the framework of the project “Bird fauna of agricultural landscape in Baltic states” (Herzon 2007) and these were located in Lääne-Viru county (three areas at Aburi and in addition Kroonu, Pandivere, Eipri, Triigi, Avispea and Pudivere), Jõgeva county (three areas at Painküla and in addition Pataste, Uhmardu, Kassema, Kudina, Süvalepa, Õuna and Siimusti) and Valga county (two areas near Kurevere, two areas at Sangaste, Lauküla, two areas at Tiidu, Lossiküla, Tagula and Korva meadow).

Study areas were with the size of 100 km². On each study area, ten areas of detailed studies with the size of 1 km² were randomly chosen from the counting network. In some areas the chosen areas had to be shifted so that the open landscape would form a sufficient ratio in the study square (at least 80%). The choice of the study squares proceeded from the fact that no area would be covered with forest more than 10% and that agricultural landscape would form no less than 80% of the area (Herzon 2007).

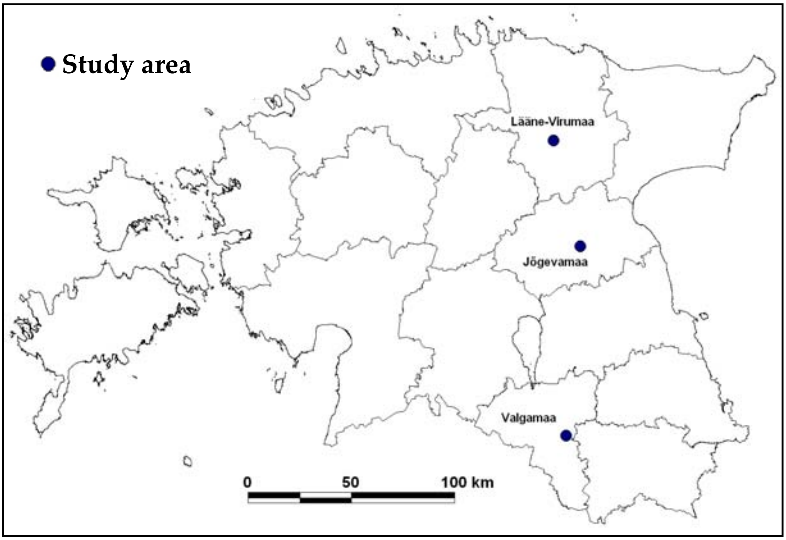

Figure 1. Schema of study areas
Joonis 1. Uurimisalade paiknemine maakondades

Each study square had four counting points that were located systematically at equal distances from the edge of the counting square with the minimum distance between points no less than 300 m. Estonian basic map (1:10 000) was used as the land use data. Land use data of the basic map (http://www.maaamet.ee) were reclassified a little proceeding, above all, from the ecologic importance of indicators on the birds of agricultural landscape. New codes were given to some of the land use types (electronic appendix 1). Primarily, the spreading of arable crops was specified. The boundaries of land parcels were specified by using land cadastre layers and orthophotos.

Counts. Point counts were used (Bibby *et al.* 1992; Bibby *et al.* 1998). Cadastre map (in 2002) and Estonian Basic Map (in 2004) in scale 1:10 000 were used as the principal map of counts. In the point marked on the map, the counter entered all encountered and heard birds within 5 minutes on the map according to the location of the bird and its activity (singing, feeding, calls *etc*.). Different codes were used to mark the activity of birds (according to Koskimies & Väisanen 1991).

In each point, the maximum number of individuals during counting was fixated. All counted birds were treated as different individuals. If in some cases it was possible to count feeding birds in several points (*e.g.* feeding Eurasian Curlews), they were counted only in one point.

Counts were implemented twice in the areas: first in the middle of May and second in the middle of June. Field works started at 5 a.m. and extended up to 10 a.m. maximum. Birds were always counted with "fine" weather in which the effect of no interfering weather factor (very strong wind, high temperature, and rainfall) was not noteworthy. The authors of the current paper, Jaanus Elts and Uku Paal, implemented Field works.

Variables. Number of species consisted of all breeding species encountered in the counting areas during two counts. Shannon's Diversity Index for species (hereinafter referred to as *H*) is commonly used for describing species in different communities which indicates the diversity of species of the area as well as the number of different species on the studied area (*i.e.* the more species there are on the study area and the more equal are their ratios in communities, the bigger is the index value; Begon *et al.* 1996).

Analysed landscape indexes. Landscape indexes are often used in landscape ecology to evaluate and describe the landscape pattern and to connect them with living organisms. The most common programme is *Fragstats* (McGarigal & Marks 1995), which was also used in the current study.

Patch density. Landscape is composed of different patch types (*e.g.* land use types). Patch density on the level of landscape shows the number of patches for area unit (calculated per 100 ha in *Fragstats*). The more there are patches in the landscape, the bigger the index value. Patch density is a good indicator of landscape fragmentation and therefore it is extremely essential in order to determine the landscape structure. Index also enables to compare different landscapes.

Edge density. An edge in landscape ecology is the boundary between two landscape classes (Farina 1998). Edge density on the level of landscape is the length of all boundaries of landscape classes per area unit. Edge density is the measure of complexity of the patch form and expresses the heterogeneity of landscape mosaic. From the point of view of landscape ecological studies, edge density and also other edge indexes are important due to the edge effect which occurs in the transition zone of landscape part or community and includes the elements of both and is therefore more complex or diverse in species than either of them (Jagomägi *et al.* 1988). For instance, there is more light at the edge area of a forest and grassland when compared to the forest and there is less light when compared to a grassland. Therefore, there are species from both communities. Some species are strongly affected by edges but other species are not affected at all (Farina 1998).

Shannon´s Diversity Index for landscape (hereinafter referred to as *SHDI*) is mainly affected by two components: number and uniformity of different land use types (their area proportion in landscape). *SHDI* is more sensitive to the number of patches *i.e.* the more there are different types of patches in the landscape the bigger is the index value. Index is sensitive towards rare types of patches (Farina 1998). Index value is 0 if there is just one patch in the landscape (*i.e.* no diversity) and the index value increases if the number of patches of different types increases and/or their division in space is becoming more uniform.

L a n d s c a p e a n a l y s i s. As the original source of landscape analysis, vectoral layers (basic areas, lines, points) of Estonian basic map were used in *MapInfo* format. All study squares and counting points were digitalized in *MapInfo*. 2-meter buffer zone had to be made around line objects and point objects so that the objects would not be lost upon rastering. After that the layers of basic objects, line objects and point objects were connected with each other in *MapInfo*. Thereafter, the layer of *MapInfo* was converted into *ArcView* programme and the counting point/study square file (vectoral format) was rewritten into raster file. 1 meter was chosen to be the length of pixel edge. Raster files in its turn were exported into *ASCII* file and after that different landscape indexes were calculated with *Fragstats* programme. Landscape indexes were calculated in three categories: (1) for each study square with the area of 100 ha, total of 30 study squares both year (10 study squares in each county); (2) for counting points around which 100-meter buffer zone was left with the area of 3.14 ha (Fig. 2) and landscape indexes were calculated (as 4 such points were located in each study square, there were total of 40 points from each county and therefore, the amount of counting points was 120 in each research year); (3) for counting points around which 200-meter buffer zone was left with the area of 12.54 ha (Fig. 2) and landscape indexes were calculated; similarly to the previous, 120 counting points were received each year.

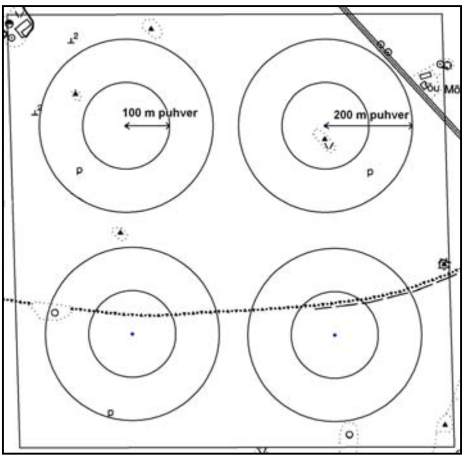

Figure 2. Buffer zones (100 and 200 meter) around the counting spot. A point inside the buffer zones represents the count spots.

Joonis 2. *100- ja 200- meetrised puhveralad ümber loenduspunktide. Punkt puhvralade keskel tähistab loenduspunkti.*

Landscape indexes were calculated on different levels because it is unclear up to now to what extent should the landscape structure be calculated around the counting spot or counting transect. Different studies have calculated the landscape structure and areas of the studied zones differently. The advantage of two buffer zones with different sizes is that just the landscape around the specific counting spot is taken into account. Disadvantage is that some species (*e.g.* Lapwings, Curlews *etc.*) may have been 250 meters away from the counting spot and their detection on bare field is not problematic. At the same time, the surrounding landscape is left out from the calculation of landscape indexes in case of 100 or 200 meter buffer zone but the buffer zones could not have been made larger than 200 meters as this way they would have "merged" with each other at certain size. Concerning the level of details of the basic map used in the research, it would not have been sensible to make a buffer zone smaller than 100 meters as the landscape indexes could start to be inaccurate on such a small area.

Statistical data processing. As the values of variables (number of species and *H*) calculated for birds were not with standard division, rank correlation (Spearman's r) was used upon the study of connections between the variables received for landscape indexes and birds. Variables calculated for birds were analysed on different levels. Firstly, analysis was implemented in two research years separately for each county (40 counting points in each county in 100 and 200 meter buffer zone and 10 research squares). Secondly, the counting points/research squares of all counties were taken into account in total (120 counting points/30 research squares in both research year). In case of such analysis, there is a danger of pseudoreplication but it is minimal as there were only single similar spots in one square (*e.g.* only bare and monospecific fields). In terms of control, an analysis was implemented with the use of average values of 100 and 200 buffer zones by research squares. The results were generally the same (in some cases the correlation coefficients were higher and in some cases lower). Therefore, it can be stated that if pseudoreplication was the case, it did not affect the obtained results. The numbers of several species were analysed with Kruskal-Wallis comparative test of average ranks and Mann-Whitney U-test.

Results

Most numerous species in 2002 and 2004.

The numbers of breeding birds and average values of *H* in the comparison of two years in the research areas of counties have been presented in table 1. The number of the most numerous breeding bird species fluctuated in the comparison of years as well as by counties (Fig. 3). At the same time on the level of research squares only the numbers of single species differed substantially between counties by years (*e.g.* the numbers of Whinchat *Saxicola rubetra* in 2004 in Valga and L.-Viru counties: p=0.02). On the level of counting points, the numbers of Skylarks (*Alauda arvensis*) differed in Valga county in 2002 and 2004 (p=0.02). Corncrakes were more numerous in Valga county when compared to Jõgeva county (p=0.01) and L.-Viru county (p=0.05) in 2002. Differences appeared the most in case of the Whinchat: the number in both years in Valga county was considerably higher than in Jõgeva county (2002: p=0.01; 2004: p<0.001) and L.-Viru county (2002: p=0.01; 2004: p<0.001).

Table 1. Average number of species and Shannon´s H in different research areas in 2002 and 2004 (± SD).

***Tabel 1**. Liikide arvu ja Shannoni H keskväärtused maakondade uurimisaladel 2002. ja 2004. (± standardhälve).*

	Valga 2002	Valga 2004	Jõgeva 2002	Jõgeva 2004	L.-Viru 2002	L.-Viru 2004
Breeding species / *Pesitsevaid liike*						
In count point *Loenduspunktis*	24 (±2,03)	51 (±3,40)	24 (±1,90)	30 (±2,31)	23 (±2,03)	25 (±1,96)
In research square *Loendusruudus*	24 (±2,59)	51 (±3,68)	24 (±4,30)	30 (±4,01)	23 (±3,74)	25 (±2,67)
Shannon's H / *Shannoni H*						
In count point *Loenduspunktis*	1,3 (±0,49)	1,66 (±0,60)	0,58 (±0,63)	0,94 (±0,68)	0,85 (±0,62)	0,99 (±0,59)
In research square *Loendusruudus*	1,8 (±0,45)	2,3 (±0,39)	1,1 (±0,75)	1,5 (±0,56)	1,4 (±0,47)	1,5 (±0,36)

When fluctuation of numbers in the research squares of counties was compared in different years, a significant difference was only found in case of the Skylark in Valga county (M.-W. U-test: U=23, p=0.04; Fig. 3), being higher in 2002. When count points were analysed inside the counties it appeared that the points of Valga county differed as to the numbers of the Skylark (U=501.5, p<0.001) and the Chaffinch (*Fringilla coelebs*; U=600.5, p=0.01). The count points of Jõgeva county research areas differed significantly with regard to the number of the Chaffinch (U=640.0, p<0.001), the Nightingale (*Luscinia luscinia*; U=700.0, p=0.02) and the Lapwing (U=652.5, p=0.03) by years. Reliable fluctuation in the number of birds was not established in the research areas of Lääne-Viru county.

Comparisons of research squares and counting points inside counties have been specified in Appendix 1 by species.

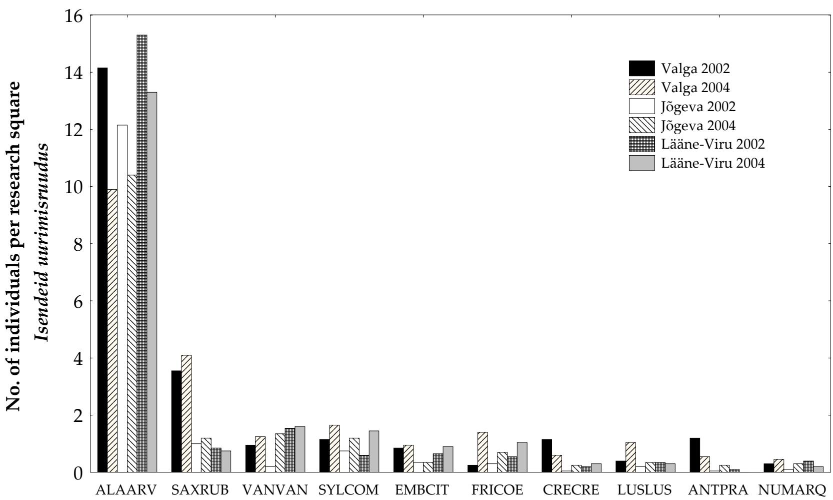

Figure 3. 10 most numerous breeding species in 2002 and 2004 in different research squares.

Joonis 3. *Kümne arvukama pesitseva linnuliigi keskmised arvukused 2002. ja 2004. aastal erinevate maakondade uurimisruutudes.*

Bird fauna diversity and landscape indexes.

Patch density calculated for the counting points of three counties (with 100 and 200 meter buffer zone) and research squares correlated significantly with the number of species as well as the species diversity (*H*), especially in 2004 in all studied counties (Table 2).

Analysing the data received from different countries (the data of counting points with different sizes as well as research squares), significant connections were revealed in all cases for the variables calculated for all birds (Table 2).

Table 2. Correlations between patch density and bird indexes (number of species and H). Statistically significant correlations are marked in bold, p≤0.05.
Tabel 2. *Eraldiste tiheduse ja lindude kohta arvutatud indeksite (liikide arv ja H) vahelised astakkorrelatsioonikordajad. Rasvases kirjas statistiliselt usaldusväärsed seosed, p≤0,05.*

	No of species *Liikide arv*		**Shannon's H** *Shannoni H*	
Year / *Aasta*	2002	2004	2002	2004
Valgamaa				
100 m buffer zone[1]/*puhverala*[1]	0.20	**0.34**	0.20	**0.40**
200 m buffer zone[1]/*puhverala*[1]	0.21	**0.40**	0.21	**0.44**
1 km² research square[2]/*uurimisruut*[2]	0.31	**0.65**	0.36	0.61
Jõgevamaa				
100 m buffer zone[1]/*puhverala*[1]	**0.44**	**0.44**	**0.41**	**0.47**
200 m buffer zone[1]/*puhverala*[1]	**0.32**	**0.57**	0.31	**0.60**
1 km² research square[2]/*uurimisruut*[2]	0.23	**0.69**	0.12	**0.65**
Lääne-Virumaa				
100 m buffer zone[1]/*puhverala*[1]	-0.04	0.12	0.00	0.14
200 m buffer zone[1]/*puhverala*[1]	**0.32**	**0.48**	**0.33**	**0.50**
1 km² research square[2]/*uurimisruut*[2]	0.50	**0.69**	0.56	**0.65**
Total / *Kokku*				
100 m buffer zone[3]/*puhverala*[3]	**0.31**	**0.40**	**0.31**	**0.43**
200 m buffer zone[3]/*puhveral*[3]	**0.40**	**0.58**	**0.40**	**0.61**
1 km² research square[4]/*uurimisruut*[4]	**0.46**	**0.80**	**0.41**	**0.82**

Sample size / *valimi suurus*: 1=40; 2=10; 3=120; 4=30.

It is noteworthy that with the increase of the area of studied areas, the connections between the number of species, *H* and patch density also increased (Table 2). Correlation coefficients were the lowest in case of counting points with 100-meter buffer zones and the biggest on 1-km² research areas. Therefore, stronger connections appeared with the increase of the area of research area.

Edge density gave considerably less reliable connections with the variables calculated for birds than patch density (Table 3). Edge density was in positive correlation with the number of breeding species as well as *H* in Jõgeva county in 2002 in 100-meter buffer zones, in 2004 in 200-meter buffer zones and in 1 km² research squares (Table 3).

Table 3. Correlations between edge density and bird indexes (number of species and H). Statistically significant correlations are marked in bold, p≤0.05.
Tabel 3. *Servatiheduse ja lindude kohta arvutatud indeksite (liikide arv ja H) vahelised astakkorrelatsioonikordajad. Rasvases kirjas statistiliselt usaldusväärsed seosed, p≤0,05.*

	No of species *Liikide arv*		**Shannon's H** *Shannoni H*	
Year / *Aasta*	2002	2004	2002	2004
Valgamaa				
100 m buffer zone[1]/*puhverala*[1]	0.09	0.11	0.09	0.17
200 m buffer zone[1]/*puhverala*[1]	0.18	0.26	0.19	0.31
1 km² research square[2]/*uurimisruut*[2]	0.23	0.31	0.36	0.32
Jõgevamaa				
100 m buffer zone[1]/*puhverala*[1]	**0.31**	0.30	0.30	**0.33**
200 m buffer zone[1]/*puhverala*[1]	0.30	**0.42**	0.28	**0.45**
1 km² research square[2]/*uurimisruut*[2]	0.25	**0.71**	0.19	**0.72**
Lääne-Virumaa				
100 m buffer zone[1]/*puhverala*[1]	-0.15	0.06	-0.10	0.08
200 m buffer zone[1]/*puhverala*[1]	0.14	0.25	0.16	0.29
1 km² research square[2]/*uurimisruut*[2]	0.09	0.48	0.35	0.53
Total / *Kokku*				
100 m buffer zone[3]/*puhverala*[3]	**0.23**	**0.30**	**0.23**	**0.33**
200 m buffer zone[3]/*puhveral*[3]	**0.33**	**0.44**	**0.33**	**0.47**
1 km² research square[4]/*uurimisruut*[4]	0.32	**0.71**	**0.37**	**0.74**

Sample size / *valimi suurus*: 1=40; 2=10; 3=120; 4=30.

At the same time, upon the analysis of counting point buffer zones with different sizes and research squares, there were reliable connections between the variables calculated for edge density and birds practically in every case (there is no significant connection between the number of species and edge density on the level of research squares in 2002).

The *SDHI* calculated for research squares was in positive correlation with the number of species as well as *H* index both years (Table 4).

Table 4. Correlations between *SHDI* and bird indexes. Statistically significant correlations are marked in bold, p≤0.05.
Tabel 4. *SHDI ja lindude kohta arvutatud indeksite vahelised astakkorrelatsioonikordajad. Rasvases kirjas statistiliselt usaldusväärsed seosed, p≤0,05.*

	No of species ***Liikide arv***		**Shannon's H** ***Shannoni H***	
Year / *Aasta*	2002	2004	2002	2004
Valgamaa				
100 m buffer zone[1]/*puhverala*[1]	0.03	0.25	0.05	0.29
200 m buffer zone[1]/*puhverala*[1]	0.16	**0.41**	0.19	**0.47**
1 km^2 research square[2]/*uurimisruut*[2]	0.44	**0.78**	0.52	**0.73**
Jõgevamaa				
100 m buffer zone[1]/*puhverala*[1]	**0.56**	0.22	**0.53**	0.24
200 m buffer zone[1]/*puhverala*[1]	**0.52**	**0.48**	**0.52**	**0.50**
1 km^2 research square[2]/*uurimisruut*[2]	0.36	0.57	0.37	**0.67**
Lääne-Virumaa				
100 m buffer zone[1]/*puhverala*[1]	-0.12	0.18	-0.07	0.18
200 m buffer zone[1]/*puhverala*[1]	0.22	**0.36**	0.26	**0.36**
1 km^2 research square[2]/*uurimisruut*[2]	**0.71**	**0.66**	**0.87**	0.60
Total / *Kokku*				
100 m buffer zone[3]/*puhverala*[3]	**0.27**	**0.30**	**0.28**	**0.33**
200 m buffer zone[3]/*puhveral*[3]	**0.41**	**0.48**	**0.42**	**0.51**
1 km^2 research square[4]/*uurimisruut*[4]	**0.59**	**0.57**	**0.58**	**0.64**

Sample size / *valimi suurus*: 1=40; 2=10; 3=120; 4=30.

Analysing the results of different counties in total (in case of counting points with different size as well as research squares), significant correlations were established in all cases for variables calculated for birds. Again, it appeared that stronger correlations appeared with the increase of the research area.

Taking into account the landscape diversity on the level of counties (average of landscape indexes of county research squares), it appeared that the landscape was the most heterogeneous in Valga county, landscape with average complexity in Jõgeva county and the landscape was the most homogeneous in Lääne-Viru research areas. This was also indicated by the data of both research years. The number of breeding species was also the highest in Valga county, average in Jõgeva county and the lowest in Lääne-Viru county (Table 1).

Discussion

The results clearly indicated that the higher the patch density, the higher the species diversity. The explanation may lie in the fact that the more there are different patches (bushes, piles of stone, edge areas of ditches), which are the habitats (location of nests, location of singing *etc.*), places of feeding, shelters, the bigger the diversity of birds. It also allows us to conclude that the more complex the landscape (many patches), the bigger the diversity of birds. In case of patch density a tendency occurred – calculating with a too small area around counting point does not give sufficiently adequate information about the landscape structures significant for birds. In Lääne-Viru county, which had the bleakest areas, in one case the correlation, was even negative in case of the number of species.

Bennett *et al.* (2004) defined edge species as species preferring different ecotones (*e.g.* the edge of field and forest, the edge of field and water body). In case of edge density the connections were positive in most cases, however, without any statistically significant correlations. The disadvantage of edge density is that the index takes into account all different edges, which might not be significant for bird's altogether. Moreover, in case of 100-meter buffer zones, the correlations were the opposite of what was expected in a couple of cases in Lääne-Viru county in 2002. Most likely, the reason was that the landscape indexes calculated for such small area do not assess the complexity of landscape adequately with the given level of details. However, it must be considered that the edges (ecotones) are extremely important breeding areas, singing areas and shelters for many birds of agricultural landscape. At the same time it needs to be stressed that not all species of agricultural landscape are dependant on edge. Maybe it is the reason why in comparison with patch density, considerably fewer connections were established between edge density and diversity of birds. Other authors (Fauth *et al.*, 2000; Howell *et al.* 2000; Bennett *et al.* 2004) have also detected a positive correlation between edge species and ecotones, however, not always (Howell *et al.* 2000). Similarly with patch density, the results of edge density analysis showed the possible effect of landscape structure on the species diversity – the higher the edge density (more heterogeneous landscape mosaic), the higher the species diversity.

SDHI also referred that the more different patches there were in landscape (more heterogeneous landscape), the higher was the species diversity and numbers.

Comparing the landscape indexes (patch density, edge density and *SHDI*) with the data of birds (number of species and *H*), more reliable relationships were established in 2004 than in 2002. It could be connected with the fluctuation in the concentration of the most numerous species in different years. Moreover, the number of species could have been affected by the change of habitats (differences of arable crops in two research years) and possible phenological and hydrological differences between two research years. Although statistically reliable relationships did not occur in every case, connections in most of cases were logical and expected. Similar contradiction has also appeared in earlier studies. For instance, Herrando & Brotons (2002) found in Spain (point counting in 4 km^2 area) that there was no reliable connection between the birds of agricultural landscapes and patch density. At the same time, such connection has been established for forest birds (Brotons *et al.* 2002). Green & Baker (2003) found for example in the United States that the density of houses and roads have a significant negative effect on species diversity which demonstrates the effect of human disturbance on the general species diversity. They also found that when the density of bushes increased, the general diversity of species also increased. Still, for example Mitchell *et al.* (2006) found a positive correlation between the species diversity and density of roads.

Results of the current paper confirm the results of Pino *et al.* (2000) in which it was found that in landscapes where strips of forest dominate, the diversity of breeding and wintering bird species is connected with the landscape diversity and patches that ensure the heterogeneity of landscape. The results of Mitchell *et al.* (2006) also conclude that the heterogeneity of forests ensures the general diversity of bird fauna. Clergeau *et al.* (1998) also found that the diversity and density of habitats and flora increases the diversity of bird fauna in cities. Heikkinen *et al.* (2004) found a positive connection between the landscape diversity and the number of all breeding pairs.

In the present study, different areas in most cases rendered similar connections in case of variables calculated for birds. Only upon the analysis of landscape indexes with 100-meter buffer zones, the results of Lääne-Viru county and Valga county in 2002 were somewhat different from other connections received. Therefore, caution should be applied with regard to landscape indexes calculated for such a small area as it might lead to wrong conclusions. Mayer & Cameron (2003) studied the species diversity and diversity with landscape indexes in research areas of different size (50 m, 100 m, 500 m, 2500 m, 5000 m buffer zones around 40 km counting transects). Upon the use of the same data they established negative correlations with birds in case of some areas and positive correlations in other cases. Even more, different bird groups rendered different results in case of the same areas.

Söderström & Pärt (2000) found that the mosaic nature of a landscape and the number of the birds of agricultural landscapes depend on the size of the research area as well as the group into which the species belong (species of forest edges or field edges, specialized field species *etc*.). In the given work, the species were not divided into groups in case of the variables calculated for birds but reliable connections with landscape indexes appeared in all studied areas. It is possible that there would have been more reliable connections if the species had been classified respectively.

The connections found between the variables calculated for birds and landscape indexes in this article support the results of Howell *et al.* (2000) according to which higher fragmentation of patches ensured by landscape objects (piles of stone, ditches, hedges, yards etc) mainly in fields and their surroundings in Estonian agricultural landscape may increase local diversity of species. Thus, the possibilities of different niches for species increase and the number of habitats and microhabitats increases. Fragmentation increases the extent of edge habitats, which is important for many arable land bird species, for instance the Grasshopper Warbler (*Locustella naevia*), Yellowhammer (*Emberiza citrinella*) and Whitethroat (*Sylvia communis*).

Upon the received results it may be concluded that different land cover types (different arable crops) and heterogeneity of landscape ensure the diversity of farmland birds in Estonian agricultural landscape and it also supports the results of Atauri & de Lucio (2001) and Brotons *et al.* (2003). Analyses similar to the present work have been made with regard to forest birds (Donovan & Flather 2002) in which connections were found between the number of several forest birds and different landscape indexes.

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Põllumajandusmaastiku linnustiku mitmekesisuse seosed maastikuindeksitega

Käesolevas artiklis on seostatud põllumajandusmaastiku lindude liigilist mitmekesisust erinevate maastikuindeksitega. Uurimisalad paiknesid kolmes maakonnas: Valgamaal, Jõgevamaal ja Lääne-Virumaal. Igal uurimisalal teostati juhuslikult valitud 10-es uurimisruudus (igas ruudus paiknes 4 loenduspunkti), punktloenduse metoodikaga 2002. ja 2004. aastal kaks loendust. Maastiku andmetest kasutati vektorkujul Eesti põhikaarti, mida klassifitseeriti ümber lähtuvalt maastikuelementide ökoloogilisest tähtsusest põllumajandusmaastike lindudele. Vektorandmed rasteriseeriti ning seejärel arvutati maastikuindeksid: eraldiste tihedus, servatihedus, Shannoni maastiku mitmekesisuse indeks. Kõik maastikuindeksid näitasid, et kõige heterogeensem oli uurimisruutude maastik Valgamaal, Jõgevamaa alad olid keskmise heterogeensusega ning kõige homogeensem oli maastik Lääne-Virumaal. Selgus, et Eesti põllumajandusmaastiku linnustiku mitmekesisus ja maastikustruktuur (väljendatuna maastikuindeksite kaudu) on omavahel seotud. Pea kõikidel uuritud juhtudel ilmnes, et suurema pindala kohta arvutatud maastikuindeksid korreleerusid lindude muutujatega tugevamini. Korrelatsioonikordajad olid madalaimad 100 m puhveraladega loenduspunktides ja suurimad 1 km^2 uurimisaladel. Tulemus viitab sellele, et liiga väike ala loenduspunkti ümber ei pruugi anda piisavalt adekvaatset infot lindude jaoks olulistest maastikustruktuuridest. Uuring kinnitab varasemaid tulemusi, et eraldiste suurem fragmentaarsus võib suurendada kohalikku linnurikkust.

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Appendix 1. Abundance differences of most numerous species in 2002 and 2004 in research squares (n=10) and count points (n=40) in different counties (Mann-Whitney U-test). Significant differences are marked in bold, p≤0,05.

Lisa 1*. Arvukamate liikide arvukuste erinevused maakondade kaupa kahe aasta võrdlused uurimisruutude (n=10) ja loenduspunktide (n=40) tasandil (Mann-Whitney U-test). Rasvases kirjas olulisused seosed, p<0,05.*

		n=10		n=40	
Lääne-Virumaa		**U**	**p**	**U**	**p**
Põldlõoke	ALA ARV	33.0	0.20	685.0	0.25
Sookiur	ANT PRA	40.0	0.45	760.0	0.15
Rukkirääk	CRE CRE	43.5	0.62	758.5	0.44
Talvike	EMB CIT	42.5	0.57	762.0	0.63
Metsvint	FRI COE	48.0	0.88	690.5	0.15
Ööbik	LUS LUS	40.0	0.45	780.5	0.75
Suurkoovitaja	NUM ARQ	40.5	0.47	738.5	0.28
Kadakatäks	SAX RUB	42.0	0.55	767.5	0.65
Pruunselg-põõsalind	SYL COM	35.5	0.27	662.5	0.11
Kiivitaja	VAN VAN	44.5	0.68	723.5	0.39
Jõgevamaa		**U**	**p**	**U**	**p**
Põldlõoke	ALA ARV	40.0	0.45	721.0	0.43
Sookiur	ANT PRA	34.5	0.24	720.0	0.09
Rukkirääk	CRE CRE	49.0	0.94	740.0	0.17
Talvike	EMB CIT	41.5	0.52	783.0	0.78
Metsvint	FRI COE	28.5	0.10	640.0	**0.00**
Ööbik	LUS LUS	35.0	0.26	700.0	**0.02**
Suurkoovitaja	NUM ARQ	34.0	0.23	739.0	0.16
Kadakatäks	SAX RUB	48.5	0.91	728.0	0.38
Pruunselg-põõsalind	SYL COM	32.5	0.19	680.5	0.15
Kiivitaja	VAN VAN	33.0	0.20	652.5	**0.03**
Valgamaa		**U**	**p**	**U**	**p**
Põldlõoke	ALA ARV	23.0	**0.04**	501.5	**0.00**
Sookiur	ANT PRA	43.0	0.60	704.0	0.24
Rukkirääk	CRE CRE	35.0	0.26	643.5	0.07
Talvike	EMB CIT	48.0	0.88	739.0	0.48
Metsvint	FRI COE	28.0	0.10	600.5	**0.01**
Ööbik	LUS LUS	31.0	0.15	656.5	0.06
Suurkoovitaja	NUM ARQ	49.0	0.94	766.0	0.57
Kadakatäks	SAX RUB	47.0	0.82	655.0	0.15
Pruunselg-põõsalind	SYL COM	34.5	0.24	675.0	0.17
Kiivitaja	VAN VAN	46.5	0.79	776.5	0.76