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What are the important landscape components for habitat selection of the ortolan bunting *Emberiza hortulana* in northern limit of range?

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ABSTRACT

Ortolan buntings *Emberiza hotulana* have undergone one of the most severe population declines of any European farmland bird over the last thirty years. The aim of this study was to find out which habitat features, including crop characteristics, ortolan bunting prefers in Estonia in breeding areas. This study compared currently occupied and unoccupied ortolan bunting territories. Occupied areas contained significantly more tall broadleaf trees, crop types, structural elements (trees, bushes, roads, overhead power lines and buildings) and spring wheat, but also had lower crop drilling densities. Ortolan bunting territories were best described by a logistic regression model containing six variables: amount of structural point elements, length of power lines, amount of tall broadleaf trees and number of different crops had a positive effect, whereas crop density and area of autumn-sown crops had a negative effect. Based on the findings of this study, the following conservation measures can be recommended: lower crop densities; spring rather than autumn-sown crops; small-field systems containing a variety of crops; scattered scrub preserved or planted; habitat patches of permanent grasslands, hedges and tall broadleaf trees retained within the agricultural landscape.

KEYWORDS

Emberiza hortulana – crop characteristics – Estonia – habitat preference – landscape elements

INTRODUCTION

The decline of farmland birds across Europe has received much attention during the past decades, and many populations are continuing to decline (European Bird Census Council, 2015). There is an agreement that the population declines of farmland birds in Europe have been driven by intensified agricultural practices, which have led to the loss and the degradation of habitats (Batáry et al. 2010; Tryjanowski et al. 2011). Mosaic rural landscape has disappeared and is now replaced with large arable monocultures (Lefranc 1997), but different pattern between western and eastern part of the continent was observed (Tryjanowski et al. 2011; Sutcliffe et al., 2015).

During the past 30 years, the number of farmland birds in Europe has decreased by a half; at that, the population of ortolan bunting (hereafter ortolan) *Emberiza hortulana* L. has decreased particularly drastically – 89% (PECBMS 2015). The ortolan is a migrant passerine bird of the size of a sparrow that nests on the ground on dry open landscapes and eats insects and plants. In Estonia, the numbers of ortolans are also rapidly decreasing (Elts et al. 2013). European (including also Estonian studies) alike have demonstrated that the disappearance of birds whose habitats are on grasslands is largely connected to the increasingly intense agricultural production (Donald et al. 2001; Herzon et al. 2008) because it significantly decreases the feeding and nesting opportunities of grassland birds and could even cause direct poisoning because of pesticides (Newton 2004). It is not clear what kind of agricultural changes have influenced the number of ortolans the most because there are still several gaps in understanding their habitat preferences (Menz & Arlettaz 2012). However, from the point of view of planning the protection of ortolans, it is important to ascertain what kind of environmental conditions should be valued regarding landscapes and what kind of changes should be made in agricultural practices.

The habitat selection by ortolan differs between various regions of Europe; the choices can be generalised into four

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habitat types. In the Mediterranean region, the ortolan prefers slanting southern mountain slopes; often, it also nests on grasslands and pastures, as well as arable land, sparse bushes and burnt woodland (Fonderflick et al. 2005; Morelli 2012). In Central Europe, more precisely, in Switzerland, Hungary, Austria and the Czech Republic, the ortolan also likes sunny slopes; here, it prefers the ones that are primarily near orchards, vineyards and small fields (Pollheimer 1998; Revaz et al. 2005; Magyar 2009; Šimeček 2009). In Sweden and Norway, most of the territories are located on clearings, burnt woodland and bogs; however, the birds might also feed on cornfields (Dale 2000; Ottvall et al. 2008). In Germany, Poland, Lithuania, Estonia and South Finland, the main habitat type is a cornfield next to ligneous plants on a heterogeneous landscape (Rootsmäe & Veroman 1974; Goławski & Dombrowski 2002; Kurlavičius 2003; Vepsäläinen et al. 2005; Bernardy et al. 2008). In case of all four regions (granted, with a few exceptions), the habitats have certain similarities: dry soil, ligneous plants used as singing perches, the proximity of arable land or pastures and a ground that is partly free of vegetation.

In Europe, the habitat choices of the ortolan are mostly connected to the fields; therefore, many studies have researched the habitat preferences in regard to various arable crops. Based on current literature review, it is hard to say whether some of the crops are highly preferable because most articles concentrate on several preferred crops, and the studies that were conducted in various regions are occasionally contradictory (Table 1). The fact that statistically preferred crops are different in different countries could be an indication of the specificity of small samples, or the lack of specific requirements by the species, as well as be related to a relatively opportunistic behaviour by the species (e.g. Menz et al. 2009b; Morelli 2012).

The aim of this study is to clarify the habitat preferences of the ortolan in Estonia. This research paper has two main hypotheses related to the choice of a habitat. Although the ortolan and many other grassland birds like a general heterogeneity of a landscape (Benton et al. 2003; Vepsäläinen et al. 2005; Berg 2008), it is likely that (1) the proportions of certain landscape components and uses of land are more significant in the selection of a habitat than others. Agricultural fields are the main feeding ground for the ortolan and, frequently, also the nesting ground (Conrads 1969; Deutsch & Südbeck 2009), and therefore, (2) the type, density and height of arable crops play an important role in selecting a habitat. In the past, the results of the preferences of arable crops have been diverse and, at times, contradictory, and the connection between the density and height of the crop and the choice of a habitat has been little studied. When organising practical protection, it is important that the applied conservation measures would correspond to the scale that interests us in order to achieve the targeted results.

In order to test our hypotheses, the ortolan habitats that were discovered during field studies were compared to random areas with a similar size, which are not habited by ortolans, and are located in the vicinity. This paper mostly concentrates on various environmental variables that could be significant for the choice of habitats of ortolans based on relevant publications in order to ascertain which of these are represented in the habitats to a greater or lesser degree. The differences could also be reflected in a direct or indirect preference of environmental traits. Based on the results, possible protection measures are proposed.

1. METHODS AND MATERIALS

1.1. Description of study areas

The territories of the ortolan were obtained from the fieldwork maps of the Bird Atlas project of the Estonian Ornithological Society and from the random observations of the Estonian eBiodiversity database (Estonian eBiodiversity database, 2013). In order to analyse the parameters of arable crops, areas in use had to be found, and the necessary measurements had to be conducted in a relatively short time period. Because of fieldwork time limitations, the areas where the density of the ortolan population is known to be low or even zero (South Estonia and the islands) were not visited. In the course of field study, approximately 120 places with previous records of the species were checked in Estonia in 2013. At every observation point, an attempt to verify the existence of the ortolan was made in the course of 10–15 minutes. Under good conditions, the ortolan song can be heard from a distance of 300 m. If a bird was found, a field research form was filled out, the location of the bird was marked on the map in MapInfo (MapInfo Professional 11.5 2012) program, where in addition, a buffer with a radius of 200 m (or about 12.5 ha area) was created that was considered to be the bird's territory where further measurements had to be conducted. Based on relevant resources, the territories of ortolans have an average radius of about 100–300 m (Conrads 1969; Vepsäläinen et al. 2007).

In the course of fieldwork, 33 occupied territories were discovered. For every observation point (territory) a random reference point (unpopulated area) was generated. Reference points were created with the MapInfo tool called *Disperse*, which formed a random new area in the vicinity of each original area (ortolan territory). Reference points could be 360 degrees in relation to the original point and within a radius of 600–1,500 m. In order to create a reference point, a buffer with a radius of 200 m was formed around the reference point. It was verified that the reference areas would not overlap with territories of other ortolans or other reference areas. Reference areas that were generated in a completely ecologically unsuitable environment (e.g. in a body of water or a forest clearly covering over half of the area) were relocated to a new random area.

1.2. Data

The first field study session took place from 1 until 15 June, 2013. Fieldwork usually began at 7 am and lasted until late at

Table 1. Preference and avoidance of different field crops by the ortolan bunting according to published literature (14 articles).

Field crop	Preference	Avoidance
Rye	Conrads 1969; von Bülow 1990; Deutsch & Südbek 2009; Hänel 2004; Bellenhaus 2007; Bernardy et al. 2008	
Potato	Revaz et al. 2005; Bernardy et al. 2008; Danzl & Lentner 2009; Deutsch & Südbek 2009; Sondell et al. 2011	
Oat	Dale & Olsen 2002; Hänel 2004; Bellenhaus 2007; Deutsch & Südbek 2009; Revaz & Spaar 2009	Morelli 2012
Wheat	Conrads 1969; Hänel 2004; Bellenhaus 2007; Deutsch & Südbek 2009; Morelli 2012	
Barley	von Bülow 1990; Hänel 2004; Deutsch & Südbek 2009	
Maize	Bellenhaus 2007; Menz et al. 2009b	van Noorden 1991; Hänel 2004; Deutsch & Südbek 2009
Rape	Bellenhaus 2007	Hänel 2004; Deutsch & Südbek 2009
Other	pea - Bernardy et al. 2008; triticale - Deutsch & Südbek 2009; sunflower, alfalfa - Morelli 2012; peet - Bellenhaus 2007; mustard - Bellenhaus 2007	

evening, under good weather conditions. The territories and their corresponding reference points were visited on the same day in order to make the data of arable crops comparable.

First, the singing perch was marked down (the place where the singing bird was sitting) on the habitat patch, the tree species were also specified. The areas of arable crops were drawn on the map; winter and summer crops were differentiated. The height of the crop was measured in centimetres as well as the density (the number of shoots) on random 25 × 25 cm squares (c.f. the next paragraph). In addition, the weeds present on the squares were also evaluated on a three-point scale: 1, none; 2, some; and 3, many. At least three random squares were placed on each habitat and reference area. If a bird was on the border between two crops, both crops received three random squares. If no crops were present (unsown land, fallow, farmyard) within a 100-m radius of the bird or the reference point, then the crop parameters of such area were not measured.

Random squares were placed around the habitat of a bird based on random numbers generated by a computer. The first random number helped to select the movement direction from the starting point, and the second helped to determine the distance of movement in the range between 1 and 15 m. Based on the same logic, the location of the next two random squares was also selected; however, in these instances, the starting point was the first random square. The frame was placed on the ground by tossing it blindly. If the location of a random square happened to be in an unusual place (e.g. a tree or an unsown strip), a new location was randomly selected. Using the reference point as a starting point, the height and density of crops were measured in reference areas based on the same methodology.

The second fieldwork session took place from 8 until 14 July, 2013. In the course of this, all of the habitats that were discovered, as well as reference areas were visited again in order to record their arable crops, and if necessary, adjust the lines of crops that were marked on the map in addition to describing the composition of woods on the areas. Forest stands were characterised by the composition formula; however, contrary to the traditional approach in forestry, the formula was created based on all layers, and each species, regardless of its small representation, received an evaluation of its percentage share. Additionally, in the case of forests, only those trees that were growing maximum 10–15 m from the edge of the forest were included in the composition of a forest stand because there is no data about the ortolan venturing deep into forests.

In every area, the quantity, length or area of the landscape components was measured. For this purpose, the

2010/2011 Estonian Basic map (Maa-amet 2011) in vector format was used in MapInfo, as well as CORINE Land Cover map (EEA 2007). Similar landscape components were grouped together as aggregated variables. The names, units and principles of grouping of aggregated variables are presented in Appendix 1.

1.3. Statistical analysis

The distribution of variables that were studied was compared to the normal distribution, and as these deviated significantly from the normal distribution, non-parametric tests were used for further analysis. In order to compare landscape variables on the habitat scale (between the territories of ortolans and the corresponding reference areas), Wilcoxon signed-rank test was used.

In order to select the best predictive factors of the presence of ortolans, logistic regression was used. The dependent binary variable was the presence of ortolans (a habitat or a reference area). On the territory level, a combination of 12 variables of a habitat that had the highest explanatory capacity were selected as independent variables (power lines, point objects, line objects, density of crops, winter crops, number of crops, roads, height of crops, summer crops, buildings, late-successional hardwood, watercourses; details are given in Appendix 1). To avoid multicollinearity between environmental variables, those with strong correlation with others (Spearman rank correlation coefficient $r_s > 0.65$) were excluded from further analysis (Freckleton 2002). In order to find the best model, the additional module MuMin (Bartoń 2013) of statistical program R was used (R Core Team 2013), a model with the lowest value of BIC (Bayesian information criterion) was determined amongst all the possible combinations of given variables.

In order to determine the sensitivity (probability that the test establishes a past event) and specificity (probability that the test establishes the non-occurrence of an event correctly) of the model, the optimum maximum value that would differentiate between existence and non-existence was determined first. For this purpose, the values of sensitivity and specificity in relation to the predicted probability were entered on a diagram and the value corresponding to the intersection of the two curves was selected. To evaluate the performance of the model, we calculated the receiver operating characteristic (ROC) curve by plotting true positive points (occupied territory) against false positives with the ROCR package for R (Sing et al. 2005). The area under the resulting curve (AUC) indicates for each model the predictive performance expressed as an index ranging from 0 to 1 (DeLong et al. 1988). As the AUC exceeded the value of 0.9 (Fig. 1), the model has high predictive power (Swets 1988).

Mantel test was used to estimate spatial autocorrelation. This test evaluates the similarity between an ecological distance (difference in values of environmental variables among occupied territories and reference areas) matrix and a geometric distance matrix. If spatial autocorrelation exists, then the closer the plots are in geometric space, the more similar the values of the environmental variables should be. First, a 'global' test was performed, regardless of occupation by ortolans, and then tests for territories and reference areas were made. Package ade4 in R was used to run the Mantel tests (Dray & Dufour 2007).

2. RESULTS

2.1. The differences between environmental variables on the habitat scale

In the comparison of environmental variables of territories and reference areas, statistically significant ($p<0.05$) variables based on the Estonian Basic map were point objects, power lines, buildings and roads (Table 2). All previously mentioned variables had higher values on the territories than they were on reference areas. The significant parameters of forest stands were late-successional deciduous trees; widespread species were maple *Acer platanoides* L., English oak *Quercus robur* L., bushes belonging in the willow family *Salicaceae*, lilac *Syringa vulgaris* L. and common ash *Fraxinus excelsior* L. Besides the willow family, all the aforementioned parameters of a forest stand were represented on territories with a higher than average frequency. In case of field parameters, the expected values of the density and number of crops and summer crops were statistically significant. The territories had a higher than average number of crops and amount of summer crops; however, the density of crops was smaller (Fig. 2).

On the habitat level, the model with the best explanatory power was:

$$\text{logit}(P) = -6.05 + 6.55 \times \text{power lines} + 0.55 \times \text{point objects} + 1.59 \times \text{number of crops} + 1.21 \times \text{late-successional deciduous trees} - 0.58 \times \text{winter crops} - 0.13 \times \text{density of crops}.$$

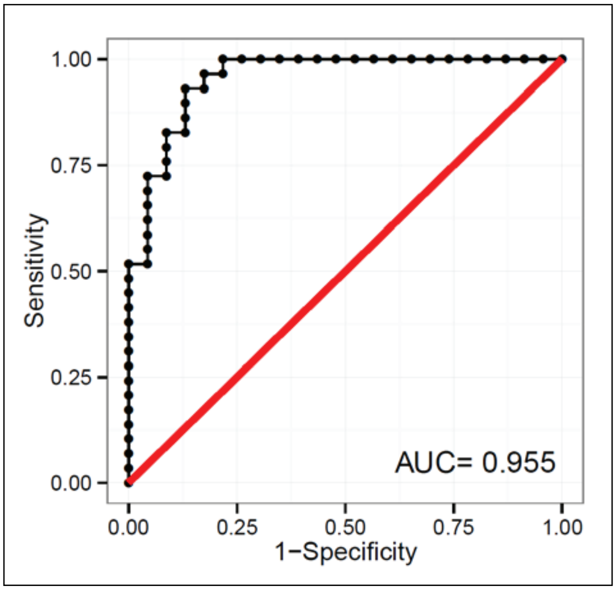

Figure 1. Receiver operating characteristic (or ROC) curve. It is a plot of the true positive rate against the false positive rate for the different possible cutpoints of a diagnostic test.

Table 2. Comparison of environmental variables in ortolan bunting territories and reference areas (n = 33, Wilcoxon sign test). Only variables with significant effects are presented (p < 0.05). Plus (+) refers to occasions when value of the variable was higher in Ortolan territories and minus (−) if smaller than in reference area.

Variable	T	Direction	p
Objects from the Estonian Base map			
No. of point objects	34	+	<0.001
Length of electric lines	46	+	0.001
Buildings	76	+	0.004
Roads	127	+	0.006
Forest parameters			
Late-successional deciduous trees	51.5	+	<0.001
Maple	46.5	+	0.003
Oak	3.5	+	0.004
Willow	19	−	0.004
Lilac	10.5	+	0.025
Ash tree	45	+	0.026
Crop parameters			
Crop density	40	−	0.009
Number of crops	58.5	+	0.027
Spring wheat	38	+	0.039

The BIC value of this model was 53.3 and evidence ratio was 3.4, compared to the second best model. This was also the only model in the range of ΔBIC < 2 which could be interpreted as the absence of equal competing models (Kass & Raftery 1995). The relative importance of variables that were not included in the model was clearly smaller across all possible models. The sensitivity of the best model was 83% and specificity was 87%. The results of logistic regression are in Table 3.

Results of Mantel tests were non-significant in 15s out of 18 case, indicating no spatial autocorrelation in most cases (Appendix 2). Previous studies in the region considering farmland birds suggested that the impact of the spatial autocorrelation on bird assemblages was not significant in samples positioned apart by at least 500 m (Piha et al., 2007; Vepsäläinen et al., 2010). That also applies well to our current analysis, and we believe that those three cases of significant results do not affect seriously our main results.

2.2. Use of singing perches

The most frequently used singing perches of ortolans were power lines (51%, Fig. 3); however, when pooling the various species of trees together (coniferous trees, late-successional deciduous trees and other deciduous trees), they were represented nearly to the same degree in 45% of cases. Late-successional deciduous trees were the second most frequent perches, other deciduous trees were the third in frequency; however, the percentage of late-successional deciduous trees was almost twice as small as the percentage of other deciduous trees in the composition of forests. In a couple of cases, coniferous trees were used as singing perches, and once, red elderberry *Sambucus racemose* L. was also used.

3. DISCUSSION

According to our results, the territories of the ortolan and reference areas are best differentiated by the combination of the following traits: the length of power lines, the number of point

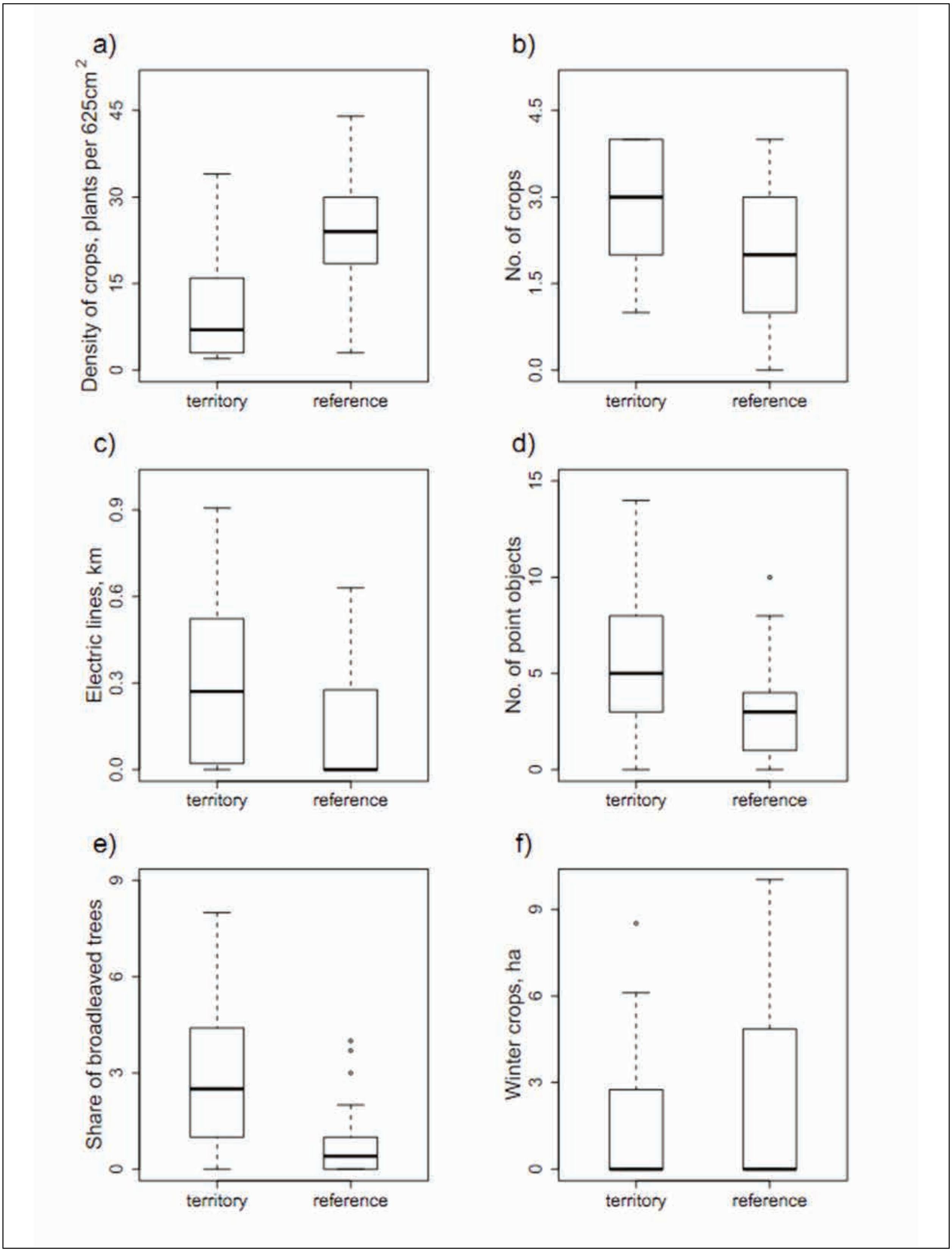

Figure 2. Comparison of medians of different landscape elements in territories (n = 33) and reference areas (n = 33). Horizontal line, median; box, quartiles; whiskers, quartiles multiplied by 1.5; points, outliers.

Table 3. The results of logistic regression model best describing habitat preferences of breeding ortolan buntings in Estonia (n = 52).

Variable	Estimate	SE	Z	p
Intercept	−6.05	3.09	−1.96	0.050
Electric lines	6.55	3.03	2.16	0.031
Point objects	0.55	0.25	2.21	0.027
Number of crops	1.59	0.79	2.01	0.045
Late-successional deciduous trees	1.21	0.50	2.43	0.015
Winter crops	−0.58	0.27	−2.19	0.029
Crop density	−0.13	0.06	−2.23	0.026

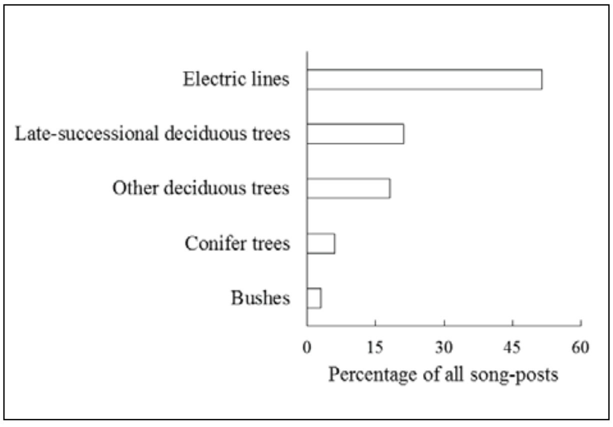

Figure 3. Frequency of different song posts (n = 33).

objects, the percentage of late-successional deciduous trees, the number of crops, the area of winter crops and the density of crops. As can be seen, the ortolan chooses its habitat largely because of the structural heterogeneity of the landscape, the type of ligneous vegetation and the parameters of crops. One of these is often not included in the studies. In only very few instances (e.g. Bellenhaus 2007; Deutsch & Südbeck 2009) has any attention been paid to the density, height and variety of crops; also, ligneous vegetation is usually described too superficially. Amongst these traits, power lines, point objects, late-successional deciduous trees and the number of crops have a positive effect on the presence of ortolans. The area of winter crops and the density of crops have a negative effect.

Contrary to several earlier studies (Menz et al. 2009a; Sondell et al. 2011; Morelli 2012) that found a positive correlation between the presence of ortolans and the presence of vegetation-free ground, this study did not find a significant link between vegetation-free ground and the choice of habitat. The height of crops was also not statistically significant, although lower vegetation might ease hunting for food (Wilson et al. 2005). In addition, the lack of height preferences is further reflected by similar proportions of winter and summer crops in populated and unpopulated areas. However, there was a strong preference for crops that were sown less densely; the reason is probably the same as in the case of vegetation-free ground – better access to food. However, it is possible that the height of a crop and vegetation-free ground, as well as the percentage of winter and summer crops could be the significant factors in selecting a habitat at other points in time, such as when arriving from migration or during the second half of summer (Vepsäläinen et al. 2005; Deutsch & Südbeck 2009). In addition, it is likely that the ortolan might move to the next neighbouring crop if one crop becomes unsuitable (Deutsch & Südbeck 2009). The possibility of this assertion is supported by the fact that the number of various crops was significantly higher on the habitats that were studied than that on the reference areas. The variety of crops also increases the variety of arthropods (Billeter et al. 2008). The only statistically significant difference between various crops (including both winter and summer crops) on habitats and reference areas was the area of summer wheat, which had a greater than average area on the territory. It is possible that in case of a bigger sample, more crop preferences would have emerged; still, based on the results of this study and various publications, it is possible to state that the ortolan is not very selective about various crops. The most important factor seems to be the environmental heterogeneity created by the co-existence of various crops on a habitat; its function could be replacing a crop that grows too dense in the course of time with a crop that is sparser.

The ortolan did not have general preferences regarding the percentage of deciduous trees, coniferous trees and bushes on the habitat level; on the other hand, late-successional deciduous trees proved to be the significant factor. Amongst the singing perches that were used, late-successional deciduous trees were represented to a significant degree as well (oak, ash and linden). Until now, various publications have emphasised the importance of oaks as a species of trees rich in larvae (Conrads 1969; Hänel 2004); however, this study demonstrated that in addition to common oaks, the ortolan habitats have higher than an average number of other late-successional deciduous trees too (particularly maple and ash). When taking into consideration that many large broad-leaved trees could have great numbers of butterfly caterpillars (Karban & Ricklefs 1983), it is possible to conclude that oaks are not the only trees that could increase the amount of food in a territory. For example, it has been shown that the Eurasian jay *Garrulus glandarius* L., who feeds mainly on the ground similarly to the ortolan, hunts for food for its young primarily on the oaks and, to some extent, also on other late-successional deciduous trees (Owen 1956). In addition, they might prefer late-successional deciduous trees because they are suitable for these birds for transmitting their song as well as spotting enemies because of their height and sparsity (Catchpole & Slater 2003).

The larger than average number of power lines and point objects in habitats is probably because ortolans use power lines and poles, single trees, larger rocks and small forest stands as singing perches as well as for roosting (Rootsmäe &Veroman 1974; Berg 2008). This is also confirmed by the fact that a little more than a half of the studied birds used power lines as singing perches; in the case of trees, late-successional deciduous trees that are often left growing individually in the middle of fields were preferred to a significant degree. Single trees are also habitats for a large number of invertebrates, and the crown and its periphery are used as a hunting ground for food by many birds and bats (Manning et al. 2006). Small forest stands growing on fields are important habitats for several rodents (Fitzgibbon 1997). The usefulness of point objects, including power poles, for birds could be related to the buffer zone around those where wild or semi-wild vegetation grows instead of a crop (Tryjanowski et al. 2014). On agricultural landscapes, a moderate amount of land that is not regularly tilled increases the habitat quality of field birds considerably, offering hidden places for nesting and an abundance of food (Fuller et al. 2004; Douglas et al. 2009).

On the ortolan territories, there were more buildings and roads than on randomly selected reference areas; based on this, it is possible to deduce that the species might benefit from human settlements to a certain extent. In addition, when comparing ligneous vegetation, the bushes belonging in the willow family were represented in habitats to a smaller degree and lilacs to a greater degree than those on the reference areas, which could be due to the active cutting down of the first and not of lilacs around human settlements. Nesting near farms has been noted in Estonia and Finland before (Piha et al. 2007; our unpublished data); however, there is no reason to think that buildings *per se* increase the attractiveness of a habitat significantly, although barns can be used as singing perches (Danzl & Lentner 2009), the heterogeneity of the landscape around farms seems to be the real contributing factor. For example, Hiron et al. (2013) have shown that the number of species and the size of populations of birds is significantly larger in the proximity of farms than on semi-wild grasslands and the so-called field islands that are usually considered to be rich in birds. Even in Estonia, a positive correlation between farmyards and the large number of bird species has been established (Elts & Lõhmus 2012). Hiron et al. (2013) explained the preference for farms with more varied possibilities for feeding and nesting, but they also admitted that the success of nesting in these areas could be theoretically lower because of a greater number of predators. The ortolan as a bird that nests on the ground is not protected from domestic cats, dogs and other synanthropic predators. The high number of roads on habitats can also be explained by the use of the typical road-side landscape components, such as trees and bushes (Berg 2008; Vepsäläinen et al. 2007). At the same time, it is possible that hunting for food on the roads could also be an influencing factor (Danzl & Lentner 2009; Sondell et al. 2011).

The avoidance of winter crops is perfectly plausible for two reasons: first, in the beginning of the breeding season, the crops that have not sprouted yet, that is, vegetation-free ground, could be preferred (Vepsäläinen et al. 2005), and second, winter crops grow high and dense quite early, and therefore, it is harder to catch invertebrates (Deutsch & Südbeck 2009). The increasing importance of winter crops because of the intensification of agriculture is endangering other species that prefer sparser and lower crops in their habitat as well. For example, growing summer crops has decreased by 80% in the United Kingdom compared to the 1970s, and the numbers of the Eurasian skylark *Alauda arvensis* L. and the stone curlew *Burhinus oedicnemus* L. has decreased by a half (Green et al. 2000; Morris et al. 2004).

Further studies of ortolans could focus on the precise use of habitats, because the current level of information about the preferences of food and feeding places, and changes in preferences during a season are not enough (Menz & Arlettaz 2012). Additionally, the current nesting preferences of the species are unknown; different factors pose a threat to nests built on ploughed land and the headlands. Very little is known about the influence of predators and competition, migration routes and wintering areas.

3.1. Recommended measures of protection

Based on the determined habitat preferences, the ortolan would benefit from

1) Raising a variety of crops on small fields in a close proximity to each other. For this purpose, small-scale agricultural production, which has significantly decreased in Estonia

compared to the 1990s, should be promoted (Statistics Estonia 2010). At that, a situation where only winter crops are grown on all fields should be avoided.

2) The density of crops should be reduced via a lower standard quantity of seeds to be sown, a larger distance between rows or a reduction of the quantity of fertilisers. Tests with winter crops regarding the habitat preferences of larks have demonstrated that compared to doubling the distance between the rows, a more efficient method is creating vegetation-free patches on the fields (Morris et al. 2004). Such patches could also improve the feeding conditions of ortolans (Gues & Pürckhauer 2011).
3) Conserving or creating field islands, lanes, hedges and single ligneous plants on agricultural landscapes. For example, widening of roads should be avoided because lanes and hedges tend to be removed because of this (Pollheimer 1998).
4) Conserving late-successional ligneous trees on fields, lanes and farms. Planting these types of trees in areas with little structural heterogeneity might be the best measure in the long run.
5) Leaving power poles on fields were the power lines are going to be removed. It is difficult to promote power lines because they are dangerous for many other bird species (Manville & Albert 2005); however, if it is necessary to construct power lines on agricultural landscapes, these should pass the areas with the least structural diversity.

Several aforementioned recommendations could be implemented with a wider support for High Nature Value farming (HNV) (Koorberg 2009). In addition, it has been demonstrated that organic farming could increase the presence of ortolans (Wolnicki et al. 2009). When allocating agri-environment support, more attention should be paid to the structural diversity of crops and landscape components and improving the competitiveness of small-scale farming. Measures increasing agricultural diversity would also benefit the rest of the biota in the respective areas (Benton et al. 2003).

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Appendix 1. The names, units and principles of grouping of aggregated variables at territories and reference areas (n = 33).

Aggregated variable	Unit	Median, quartile (25%; 75%)		Original variables
		Territory	Reference	
Objects from the Estonian Base map				
Streams	km	0.03 (0; 0.4)	0.08 (0; 0.62)	Ditch, main ditch, river
Roads	km	0.72 (0.59; 0.81)	0.39 (0.33; 0.61)	Basic road, secondary road, track/path, street
Buildings	ha	0.02 (0.01; 0.05)	0 (0; 0.01)	Dwelling, roofed area, other construction, foundation, glasshouse/greenhouse, ruins
Forest	ha	0.52 (0.03; 0.76)	0.81 (0.04; 1.95)	Forest, shrub
Yards	ha	0.47 (0.12; 0.82)	0 (0; 0.52)	Yards, production area, green area
Linear objects	km	0.19 (0.04; 0.34)	0.13 (0; 0.29)	Row of trees, stone fence, fence, concrete wall
Electric lines	km	0.27 (0.02; 0.52)	0 (0; 0.28)	Electricity transmission line
Point objects	pcs	5 (3; 8)	3 (1; 4)	Single tree, scattered trees, grove, boulder (height value), heap of stones, scattered boulders
Grassland	ha	1.57 (0.16; 2.64)	0.79 (0; 5.39)	Natural or cultural grassland
Forest edge	km	0.62 (0.35; 0.83)	0.61 (0.33; 0.95)	Edge of forests, forest patches and avenues
Crop properties				
Spring crop	ha	3.5 (1.47; 5.74)	1.61 (0; 8.38)	Wheat, barley, oat, rape
Winter crop	ha	0 (0; 2.76)	0 (0; 4.85)	Wheat, barley, rye, rape
Other culture	ha	0 (0; 1.12)	0 (0; 0)	Potato, pea, cumin, mixture of cereals, stubble
Black soil	ha	0 (0; 0.13)	0 (0; 0.04)	Not germinated culture, fallow, other disturbed areas
Density of the crop	pcs/625 cm2	7 (3; 16)	24 (17; 31)	
Crops height	cm	18 (12; 26)	20 (16; 32)	
No. of cultures	pcs	3 (2; 4)	2 (1; 3)	
Weeds	scale 1,2,3	2 (1; 2)	1 (1; 2)	
Woodland parameters				
Deciduous trees	%	7.3 (6.5; 8.6)	7 (3.9; 8)	20 species of deciduous trees
Conifer trees	%	0.5 (0.2; 2)	0.75 (0; 2)	Pine, spruce
Late-successional deciduous trees	%	2.5 (1; 4.4)	0.4 (0; 1)	Oak, ash tree, linden, chestnut, maple, elm
Bushes	%	1.5 (0.6; 2)	1 (0.3; 2.5)	16 species of bushes
No. of tree species	pcs	8 (7; 9)	7 (5; 8)	

Appendix 2. Results of the Mantel tests. Mantel test evaluates the correlation between ecological distance matrix and a geometric distance matrix. If spatial autocorrelation exists, then the closer the plots are in geometric space, the more similar is the environmental variables in compared plots should be.

	'Global' test	Territory	Reference
Electric lines	r = 0.008, P = 0.348	r = −0.03, P = 0.695	r = 0.062, P = 0.146
Point objects	r = −0.027, P = 0.755	r = 0.028, P = 0.268	r = −0.002, P = 0.465
Number of crops	r = −0.021, P = 0.758	r = 0.014, P = 0.334	r = −0.042, P = 0.795
Late-successional deciduous trees	r = 0.013, P = 0.323	r = 0.008, P = 0.386	r = 0.129, P = 0.038
Winter crops	r = 0.007, P = 0.38	r = −0.078, P = 0.939	r = 0.059, P = 0.143
Crop density	r = 0.084, P = 0.024	r = 0.159, P = 0.017	r = −0.018, P = 0.527