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## Applying trait-based community metrics of relevance to conservation for understanding community patterns of farmland birds in Northwest Russia

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## ABSTRACT

Use of community trait-based metrics has been increasingly implemented for achieving an integrated view of biodiversity in conservation planning. We examined the extent, to which the use of community metrics based on species traits reflecting plausible sensitivity to change would contribute to our understanding of landscape characteristics of importance to the conservation of farmland birds in a poorly studied region of Northwest Russia. We collected species data on farmland from 230 transects covering a total 215 km for each year of 2008, 2010 and 2011 and analysed them using generalised linear mixed modelling. We derived community indices from species traits of habitat specialisation, trophic position, relative brain size and body mass. By relating these indices to the numbers of all species regarded farmland and Species of European Conservation Concern (SPEC), and by analysing them against the type of field and occurrence in typical non-cropped landscape elements, we showed consistent, albeit weak, congruence among the taxonomic and trait-based community descriptors. All community descriptors had their lowest estimates in arable fields. Community specialisation was the highest in open abandoned fields, which confirms the importance of such fields as refuges for regionally specialised species. Pastures were characterised by the highest community biomass, which indicates a particularly good resource base. Presence of ditches, of all non-cropped elements, had the strongest positive relationship with the community descriptors. The SPEC number strongly correlated with the overall species richness of farmland birds. A relatively weak congruence between taxonomic and trait-based community descriptors highlights their complementarity in understanding the underlying mechanisms of community changes. However, similarity in patterns among field types means that, under the current level of production in the region, accounting for the species richness of farmland birds seems to be sufficient to rapidly assess community sensitivity to agricultural change.

## 1. Introduction

Considerable progress has been made describing biodiversity patterns in agricultural environments with the objective of understanding which biodiversity components are retained despite agricultural expansion and intensification within landscapes and why (Norris, 2008). Accounting for ecological differences among species is increasingly used in conservation planning aiming at an integrated view of biodiversity.

Functional indices such as functional richness, functional evenness or functional divergence (Mason et al., 2005) based on species-traits as well as indices of community-level weighted means of trait values are used to complement the taxonomic community metrics (e.g. Devictor and Robert, 2009; Guerrero et al., 2011).

Patterns obtained from taxonomic community metrics and trait-based ones for birds in agricultural landscapes may not be congruent. In France, the taxonomic, functional (i.e., based on traits such as

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species specialisation) and phylogenetic diversity metrics of the of avian communities only partly correlated at national scale (Devictor et al., 2010). Intensity of agricultural land use had differential effects on community taxonomic diversity and on community specialisation and trophic indices (Filippi-Codaccioni et al., 2010; Teillard et al., 2015). The presence of non-cropped elements in farmland promoted community species diversity but not community specialisation (Chiron et al., 2010; Filippi-Codaccioni et al., 2010). This raises the question of the complementarity of these indices and their use in conservation assessments.

Environmental or land-use changes exert varied amounts of pressure on species populations in accordance with species ecological characteristics making some species prone to decline under environmental change or disturbance (e.g. Devictor and Robert, 2009; Jennings and Pocock, 2009). Bird species were shown to be of particular sensitivity to change if they are specialised in habitat use and diet, are long-distance migrants, have relatively short incubation and fledging periods and relatively small brain size (Amano and Yamaura, 2007; Doxa et al., 2012; Filippi-Codaccioni et al., 2010; Le Viol et al., 2012; Pocock, 2011; Princé et al., 2013; Shultz et al., 2005).

Models derived for habitat association (Whittingham et al., 2007) and relationships between species traits and population trends developed in one region can be poor at inferring patterns in another region (Le Viol et al., 2012; Pocock, 2011), especially if the regions vary considerably in the dynamics of land-use changes (Sutcliffe et al., 2014). Regional studies are therefore necessary for enabling comparisons of patterns in order to assess the implied mechanism in the biodiversity responses (Pocock, 2011) and developing regional land-use strategies (Sutcliffe et al., 2014).

Research on farmland biodiversity in Eastern and Southern Europe has intensified in recent decades (Sutcliffe et al., 2014) but remains infrequent in the European part of the Russian Federation. In the 20th century, state-controlled agriculture was practiced on large fields fit for use by large production units (Liefert and Liefert, 2012), yet it never reached the levels of intensity typical of European Union production driven by the market economy and output-based subsidies (Bokusheva et al., 2012). The agricultural landscape is a mixture of field types, many under low-input use, and it is rich in non-cropped elements such as ditches and scrub. In recent decades, a revival of agricultural production has been documented in the country (Guzel, 2012). Its further intensification is supported by the state (Griewald et al., 2017) and by a growing demand for land-based biomass (Norris, 2008). Therefore, agriculture-supported habitats in the region are presently susceptible to intensification pressures that have driven wide-scale biodiversity losses elsewhere in Europe (Stoate et al., 2009). Understanding the relationships between habitat characteristics and sensitivity of the biota is a prerequisite for providing an 'early warning' system in an agriculturally important region facing intensification.

We used data on farmland bird species recorded in fields across an agricultural landscape in Northwest Russia in order to examine the extent, to which the use of community metrics based on species traits reflecting plausible sensitivity to change would contribute to i) rapid assessment of the community sensitivity to change across the land-use types in comparison to taxonomic indices and ii) to understanding of the reasons for certain characteristics of an agricultural landscape, such as field types or non-cropped elements, being of importance to the conservation of farmland birds. The traits were specialisation to habitat, trophic position, brain size and body mass. The metrics derived from each trait were community weighted mean indices and abundance of the top quartile (i.e. 25% of top values) of the traits. The taxonomic metrics were the number of farmland bird species and Species of European Conservation Concern (SPEC).

## 2. Material and methods

### 2.1. Study area

We carried out research in the Gatchinsky administrative district of Leningrad region in Northwest Russia (59° 30' N, 30° 2' E; Supplementary material, Fig. A1). The region lies in the hemiboreal zone of Europe and occupies an area of 175 116 km<sup>2</sup>. Forests make up about 65% of the district's area, farmland 28%, settlements 6% and wetlands 1%. In the northern part of the district, the soils are of a carbonate Ordovic type and have good natural drainage allowing for large fields within an open landscape. The south has mainly sod-podzolic soils with poor drainage and excess wetness, resulting in small fields fragmented by forest (Herzon et al., 2014). During the study, farmland consisted of 90 km<sup>2</sup> of arable crops, 230 km<sup>2</sup> of grassland used for hay, 50 km<sup>2</sup> of pastures used for cattle and 80 km<sup>2</sup> of fallows and abandoned fields.

Agriculture is the dominant economic activity and is practiced on 450 km<sup>2</sup> of land, of which 344 km<sup>2</sup> is arable (including sown grassland). Dairy is the main agricultural production line. Due to the district's importance as the main supplier of agricultural produce to St Petersburg, the regional production output is above the national average (Federal State Statistics Service, 2016; Supplementary material, Table A1). In terms of output in 2010, it was less productive than the Western European average (FAOSTAT, <http://faostat3.fao.org>; Supplementary material, Table A1) but comparable to that in Northern Europe (ibid.). There are no data on grassland use in the region but, according to our observations, it had several extensive features: grazing unimproved, mainly alluvial, grasslands and a single haymaking event were common, while intensive rotational grazing was rare.

### 2.2. Sampling protocol

We surveyed birds in 2008, 2010 and 2011 in a sample of 230 fields out of a total of 1224 fields (Herzon et al., 2014; Supplementary material, Table A2). We sampled survey fields randomly stratified by field type, so that the field types were represented in relation to their occurrence in the district. The numbers of the different field types slightly varied year on year due to crop rotations (Table 1). We placed one transect in the middle of each field along its longest side and crossing the opposite field edges. This resulted in 215 km of transects across 110 km<sup>2</sup> of field. No two transects were closer than 500 m from each other. We ran two counts in a season, with the central dates of mid-May and mid-June, from 7 a.m. to 11 a.m. under appropriate

**Table 1**

Description of explanatory variables used in modelling the avian community in the agricultural landscape in Northwest Russia (n = 690 with 230 fields surveyed every year).

Explanatory variables	Description <sup>a</sup>
Dominant field type	Four classes: Arable land, n = 65, 61, 53; abandoned land, n = 18, 14, 12; grassland, n = 122, 132, 139; pasture, n = 25, 23, 26.
Year	Three classes: 2008, n = 230; 2010, n = 230; 2011, n = 230.
Ditches	Three classes: No ditches, n = 318; ditches around the field, n = 287; ditches within the field, n = 85.
Bushes	Three classes: No bushes, 345; only along ditches or by stone heaps, n = 299; within field area, n = 46.
Stones	Three classes: No stones in the field, n = 339; a few stones in the field; n = 237; numerous stones in the field, n = 114.

<sup>a</sup> The number of fields within each type varied from year to year due to crop rotations or change in use.

weather conditions. Small passerines were registered within a 50m belt, while Corvidae and non-passerines were registered within a 250m belt. Individuals foraging fields and hunting overhead (such as raptors and the barn swallow (*Hirundo rustica*)) were counted but birds passing high overhead were not. Surveys were undertaken each year by the same three fieldworkers, who are professional ornithologists and underwent training in describing agricultural habitats prior to the survey.

We identified field types during the field visits each year following the detailed characteristics of vegetation and field management at a particular time period. We grouped the fields into four main types for this analysis: arable land (root vegetables, spring cereal, winter cereal, first-year sown grasses), grassland sown for fodder (monospecific grassland and multispecies grassland), pasture and abandoned fields (Table 1). We did not survey abandoned fields when a cover of scrub and trees exceeded approximately 30% of the field area regardless of abandonment duration. The final number of abandoned fields surveyed was slightly lower (ca 10%) than the average in the district because we excluded such overgrown fields without replacement.

We registered occurrence of three types of non-cropped elements in and around the field perimeter and up to 250m from it for narrow fields. These – ditches, bushes and stone heaps (also with young trees) – are characteristic of the region's field area and have been demonstrated as being important for farmland birds in neighbouring Finland and the Baltic countries (e.g. Piha et al., 2007; Herzon et al., 2008). Due to logistics we did not measure lengths and areas of each element but grouped them by the type of occurrence: 1: absent, 2: only around fields or infrequent, and 3: within fields or numerous (Table 1). There were no changes in the status across the survey years.

### 2.3. Deriving indices

For the analysis, we used data on species in habitats that can be regarded as farmland according to Tucker and Evans (1997). We also included some of the species that regularly visit fields in the study region for foraging, even if their main habitat is elsewhere (such as the common crane (*Grus grus*), black grouse (*Lyrurus tetrix*) and the Lariidae) (Table 2). We used the maximum count of individuals of the same species from two visits, which gave a rough estimate of the relative differences in the occurrence of bird species among the field types (although not breeding densities in the strict sense) (Supplementary material, Table A1).

We calculated two taxonomic indices: species richness and the SPEC number for Europe (BirdLife International, 2004). The latter was developed for the whole of Europe, including the study region, and focuses on species regarded as vulnerable based on their negative population trends or rarity. Our assumption was that this taxonomic index – implicitly linked to sensitivity of species – would tighter correlate with the metrics, based on sensitivity traits, than the overall species richness. We calculated four community indices: the community specialisation index (CSI), community trophic index (CTI), community brain index (CBI) and community biomass (Biomass). The description of each index, rationale for its use in the context of this study, calculation steps and further references are summarised in Table 3. In our dataset, brain mass data for the pale harrier (*Circus macrourus*), Montagu's harrier (*Circus pygargus*), Blyth's reed warbler (*Acrocephalus dumetorum*), common rosefinch (*Carpodacus erythrinus*) and the river warbler (*Locustella fluviatilis*) were missing. We excluded these species; they represented just 1.98% of the counted individuals.

Use of community trait indices, similarly to the use of taxonomic diversity indices, presents a general profile of the sites, allowing comparison of sites and trends. They are difficult to interpret without knowing how their components change: a low community index may result from a low number of species with high values (e.g. highly specialised

species) or a low number of individuals of many species with high value. To explore the behaviour of the trait-based indices in the study system and ease interpretation of the results, we calculated auxiliary metrics for each trait-based index – total abundances of the species within the top quartile of each of the traits. Each auxiliary metric thus represents the combined abundance of the species that are expected to be most sensitive to environmental change: most specialised species in the boreal zone, species with the top trophic position, having the smallest brain size related to the body mass, and with the largest body mass (Table 2, Table 3).

### 2.4. Modelling

We first calculated species rarefaction curves for the four field classes in order to assess possible effects of varied sampling effort in each field type on the number of registered species (Gotelli and Colwell, 2001). We assessed correlation among species trait values at the species level (Pearson correlation). We then tested to what degree the community trait-based indices relate to the taxonomic richness across all field types in the region by running parametric correlations among indices at the community (or transect) level.

Finally, we related all community descriptors to the habitat characteristics so that we could compare the patterns derived from habitat models predicting, on the one hand, the most sensitive communities (functional trait-based approach) and, on the other, most taxonomically diverse communities (taxonomic approach). We ran generalised linear mixed models (GLMMs) in R (R Development Core Team, 2016) and used the R packages MASS (Venables and Ripley, 2002) and nlme (Pinheiro et al., 2016). We controlled the effect of overdispersion using penalised quasi-likelihood (glmmPQL). We modelled nine response variables, of which four were trait-based community indices (CSI, CTI, CBI, Biomass), one taxonomic index (species richness), and four were abundances of species groups within the top quartile (highest specialisation values, at the top of the food chain, smallest brains and highest body mass). There was a particularly strong correlation between two taxonomic indices, species richness and the SPEC number ( $R^2 = 0.851$ ,  $P < .0001^{**}$ ). Since species richness correlated tighter with most of the trait-based indices, we continued with modelling only of species richness in GLMMs. We fitted six explanatory variables into the models: field type, year, type of ditch occurrence, type of bush occurrence, type of stone occurrence. We checked correlations among the explanatory variables by using the `corvif` function (R package `car`) on each full model. All variables showed a VIF value  $< 1.8$ , meaning there was no strong multicollinearity (Chatterjee and Hadi, 2006). We treated transect length (log transformed) as an offset variable, field identity by adding a random intercept (`random = ~1 | transectid`) and for temporal autocorrelation in the series of counts, by fitting year as autocorrelation function (`correlation = corAR1(form = ~year)`) to the model (Zuur et al., 2009). Our data were also spatially autocorrelated. Therefore we used the `spdep` package (Bivand and Piras, 2015) and added  $x$  and  $y$  coordinates as one covariate into the model to take account of spatial autocorrelation.

### 3. Results

All rarefaction curves reached an asymptote indicating that the sampling effort in each field type was sufficient and that species numbers, as well metrics derived from them, are comparable across field types (Supplementary material Fig. A2). At the species level, there were no significant correlations among the traits (all Pearson  $r < 0.26$ ). At the community level, most correlations among the indices across all fields were significant (Table 4). Strong correlations ( $R^2 > 0.30$ ) were between species richness and Biomass, SCI and STI, and CTI and CBI.

**Table 2**

Farmland bird species and their trait values: species specialisation index (SSI) for the boreal region, trophic score, body mass, brain mass, and brain mass residuals (residuals from regressing respective species' brain masses against brain body masses). NA denotes unavailable estimates. Species in bold are those selected into groups in the top quartile of the respective traits: most specialised, top of food chain, smallest brains, and heaviest species.

Species	SSI	Trophic score	Body mass (g)	Brain mass (g)	Brain mass residuals
<i>Acrocephalus dumetorum</i>	4.33	2.95	11.8	NA	NA
<i>Acrocephalus palustris</i>	3.93	2.95	11.9	4.40	0.18
<i>Acrocephalus schoenobaenus</i>	<b>5.03</b>	2.95	12.3	3.70	-0.011
<i>Alauda arvensis</i>	3.63	2.25	37.2	2.80	-0.152
<i>Anthus pratensis</i>	4.42	2.75	18.4	2.80	-0.228
<i>Apus apus</i>	4.33	<b>3.00</b>	39.7	0.61	-0.586
<i>Asio flammeus</i>	3.60	<b>3.00</b>	320.0	NA	NA
<i>Buteo buteo</i>	NA	<b>3.90</b>	<b>806.5</b>	0.80	0.48
<i>Carduelis cannabina</i>	2.98	2.05	15.3	4.10	0.22
<i>Carduelis carduelis</i>	2.84	2.00	15.6	4.80	0.05
<i>Carduelis chloris</i>	2.84	2.05	27.8	3.70	0.02
<i>Carpodacus erythrinus</i>	2.66	2.10	24.1	NA	NA
<i>Ciconia ciconia</i>	4.16	<b>3.60</b>	3406.3	0.50	0.12
<i>Circus aeruginosus</i>	<b>5.03</b>	<b>4.00</b>	<b>584.5</b>	1.00	0.37
<i>Circus cyaneus</i>	<b>5.03</b>	<b>4.00</b>	<b>414.2</b>	1.00	0.41
<i>Circus macrourus</i>	NA	<b>4.00</b>	377.7	NA	NA
<i>Circus pygargus</i>	4.24	<b>3.60</b>	310.2	NA	NA
<i>Columba livia</i>	<b>6.89</b>	2.01	288.5	0.70	-0.063
<i>Columba palumbus</i>	2.49	2.01	<b>490.0</b>	0.50	-0.453
<i>Corvus cornix</i>	2.91	2.63	<b>570.0</b>	1.80	-0.050
<i>Corvus frugilegus</i>	2.98	2.11	<b>488.0</b>	1.80	0.05
<i>Corvus monedula</i>	3.09	2.75	233.4	2.40	0.03
<i>Coturnix coturnix</i>	<b>6.33</b>	2.22	101.5	0.90	-0.360
<i>Crex crex</i>	<b>6.33</b>	2.90	157.0	0.90	-0.298
<i>Delichon urbica</i>	5.03	<b>3.00</b>	19.6	0.44	-0.380
<i>Emberiza citrinella</i>	3.12	2.30	26.5	2.80	-0.047
<i>Emberiza schoeniclus</i>	4.08	2.95	18.3	3.70	0.22
<i>Falco tinnunculus</i>	2.42	<b>3.85</b>	217.0	1.90	0.65
<i>Gallinago gallinago</i>	<b>5.14</b>	<b>3.00</b>	116.0	1.20	0.07
<i>Gallinago media</i>	4.33	<b>3.00</b>	187.2	1.00	0.18
<i>Grus grus</i>	3.25	2.12	<b>5113.0</b>	0.30	-0.003
<i>Hirundo rustica</i>	3.00	<b>3.00</b>	19.1	0.55	-0.134
<i>Lanius collurio</i>	3.80	<b>3.15</b>	29.9	3.60	0.17
<i>Larus argentatus</i>	3.25	<b>3.15</b>	<b>1014.5</b>	0.60	-0.022
<i>Larus canus</i>	2.44	<b>3.65</b>	<b>413.1</b>	0.90	0.26
<i>Larus fuscus</i>	4.33	<b>3.00</b>	<b>813.5</b>	0.70	0.15
<i>Larus ridibundus</i>	2.64	<b>3.00</b>	247.8	1.00	0.26
<i>Limosa limosa</i>	<b>5.21</b>	2.95	307.5	1.00	0.16
<i>Locustella naevia</i>	<b>5.14</b>	<b>3.00</b>	13.3	3.60	0.24
<i>Lyrurus tetrix</i>	<b>5.03</b>	2.05	<b>1102.4</b>	0.40	-0.542
<i>Motacilla flava</i>	4.24	<b>3.00</b>	13.9	3.00	-0.138
<i>Numenius arquata</i>	4.42	<b>3.00</b>	814.0	0.60	-0.192
<i>Numenius phaeopus</i>	<b>4.62</b>	<b>3.00</b>	<b>420.5</b>	1.00	-0.598
<i>Oenanthe oenanthe</i>	4.33	2.95	22.3	3.10	-0.027
<i>Passer domesticus</i>	2.16	2.12	27.4	3.10	0.09
<i>Passer montanus</i>	<b>5.03</b>	2.15	22.0	2.80	0.09
<i>Perdix perdix</i>	3.56	2.10	381.0	0.50	-0.621
<i>Pica pica</i>	2.79	2.51	166.0	3.00	0.53
<i>Saxicola rubetra</i>	<b>5.45</b>	<b>3.00</b>	16.6	3.90	0.18
<i>Sturnus vulgaris</i>	2.79	2.50	79.9	2.40	-0.096
<i>Sylvia communis</i>	<b>4.81</b>	2.60	14.5	4.50	0.02
<i>Tringa totanus</i>	<b>4.68</b>	<b>3.00</b>	121.5	1.40	0.04
<i>Turdus pilaris</i>	4.33	2.60	104.0	2.10	-0.253
<i>Vanellus vanellus</i>	4.33	2.90	226.0	1.10	0.03

All abundances of species groups within the top quartile strongly inter-correlated.

In all taxonomic and trait-based profile indices, except CBI, as well as in abundances of all species groups most sensitive to change, estimates for some of the main field types were significantly different from the reference line of abandoned field (Table 4, Supplementary material Fig. A3). All estimates for arable fields had consistently the lowest values among all field types and were significantly lower, except for the abundance of heaviest species, compared to abandoned fields (Table 5). Grassland had a significantly lower abundance of most specialised species and of top of the food chain species and a lower species richness than abandoned fields. In contrast, in pastures, the species richness

was similar to that in abandoned fields, but Biomass, as well as abundances of the heaviest species and species at the top of the food chain, were significantly the highest. The level of CSI and the abundances of most specialised species were statistically lower than in abandoned fields.

Fields with ditches across had significantly higher Biomass, abundance of species with the highest specialisation values, species at the top of the food chain, and relatively lightest brains than fields either without ditches and/or ditches at the field perimeter (Table 5). In contrast, bushes within fields negatively related to Biomass, abundance of species at the top of the food chain, and to the heaviest species but related positively to the abundance of species with the relatively lightest

**Table 3**

Community trait-based indices applied to the community of farmland bird species in NW Russian Federation: description, rationale for its use in the context of the study, calculation steps and references for each index and its application examples. Species-specific values are provided in Table 2.

Index and definition	Rationale	Calculation steps	References and examples of applications
Community specialisation index (CSI) = average niche width (habitat) of species within the community weighted by species abundances	Reflects the relative abundance of more- or less-specialised species in local assemblages, and is expected to be high for communities with a relatively high number of specialists. Although bird species are generally able to utilise a variety of resources across the landscape, bird communities appear to be well defined along a specialist-generalist gradient (Julliard et al., 2006).	<ol style="list-style-type: none"> <li>1. Obtain information on species' preference for 11 main-level habitat types (from the European Nature Information System, EUNIS; <a href="http://eunis.eea.europa.eu">http://eunis.eea.europa.eu</a>). Levels of preference are coded by experts as: 3: primary habitats, 2: secondary, 1: others.</li> <li>2. Select levels specified for continental or boreal Europe and retain the highest level per species for each habitat.</li> <li>3. Calculate species specialisation index (SSI) as the coefficient of variation of the species affinity across the range of habitat classes.</li> <li>4. Calculate CSI for each transect each year as the average specific specialisation index of all individuals detected, i.e. the average SSI of detected species weighted by local species abundance as: <math>CSI = \sum(ai \cdot SSI_i) / \sum(ai)</math>, where <math>ai</math> is the abundance of species <math>i</math>.</li> </ol>	<p>Julliard et al. (2006)</p> <p>Devictor et al. (2008) Detecting spatial (Devictor et al., 2008; ) and temporal (Le Viol et al., 2012) change in community composition; establishing relationships to past and present land-use intensity (Doxa et al., 2012; Princé et al., 2013; Teillard et al., 2015; Dross et al., 2017); exploring effects of habitat structure (Filippi-Codaccioni et al., 2010). Pellissier et al. (2013).</p>
Community trophic index (CTI) = average trophic score of all species within the community weighted by local species abundances	The species score reflects the species position in a simple food chain. The index indicates a larger range of resources allowing for species at every trophic level, including species at its top, which may indicate that the communities are highly functional (Mouysset et al., 2012). Species on the top trophic level tend to be dietary specialists (may consume a variety of prey species but do not take plant-based food) – the trait strongly related to species sensitivity to land use (Newbold et al., 2013).	<ol style="list-style-type: none"> <li>1. Obtain the proportions of plant, invertebrate and vertebrate items in the diet of each bird species (from Cramp et al., 1977–1994).</li> <li>2. Weight proportions as 1, 2 and 3 for plant, invertebrate and vertebrate items, respectively, as well as by changes in diet during the life cycle to obtain a species-specific trophic score.</li> <li>3. Compute the index (equation as for CSI).</li> </ol>	<p>Determining effects of agricultural intensification on bird communities (Teillard et al., 2015); bio-economic spatially explicit modelling (Mouysset et al., 2012).</p>

Table 3 (Continued)

Index and definition	Rationale	Calculation steps	References and examples of applications
Community brain index (CBI) = average brain mass related to body mass of all species within the community weighted by local species abundances abundance	Is expected to reflect the capacity of species to respond behaviourally to environmental change: the relative brain size of bird species is demonstrated to positively relate to population trend (Shultz et al., 2005) and capacity to innovate (Ducatez et al., 2014). The low values thus indicate predominance in the community of species with lower adaptive response to a highly disturbance environment and plausible sensitivity to changes.	<ol style="list-style-type: none"> <li>1. Obtain data on the brain mass (Mlíkovský, 1989a, 1989b, 1989c, 1990; Galván and Møller, 2011a, 2011b) and body mass of species (Cramp et al., 1977–1994); unsexed birds or mean between the sexes.</li> <li>2. Run the regression of log(brain mass) against log(body mass) separately for passerine and non-passerine species in order to control positive correlations between the two masses, and to account for a likely evolutionary shift in relative brain sizes between the two groups.</li> <li>3. Calculate the residuals from the regressions.</li> <li>4. Compute the index (equation as for CSI) on the residuals.</li> </ol>	Shultz et al., 2005 for the species-level scores.  Exploring relationships to population trend (Shultz et al., 2005); assessing capacity of birds to innovate (Ducatez et al., 2014). Not used as a community index. Wiens, 1989, p. 433.
Community biomass, or bird standing crop biomass = biomass of all individuals in a community	Indicates the energy resources of the environment (Wiens, 1989) and inclusion of heavy species. The latter are shown to be sensitive to forest use intensity (Newbold et al., 2013). In farmland, large-bodied passerines (mainly, Corvidae) did not undergo worst population declines, plausibly, due to their trophic generalism (Pocock, 2011).	<ol style="list-style-type: none"> <li>1. Obtain data on the species body mass as above.</li> <li>2. Calculate the sum of the products of the abundance of each species multiplied by the body mass of the species for all species recorded in a transect.</li> </ol>	Contrasting organic management to conventional (Piha et al., 2007).
Abundances of the species within the top quartile of each species-specific score: SSI, trophic scores, brain mass and body mass.	<p>Species most specialised to the boreal zone, auxiliary metric to CSI.</p> <p>Species having the top trophic values, auxiliary metric to CTI.</p> <p>Species with the relatively smallest brains, auxiliary metric to CBI.</p> <p>The heaviest species, auxiliary metric to Community biomass.</p>	<p>Summarise abundance of the species within the top quartile of SSI values.</p> <p>Summarise abundance of the species within the top quartile of trophic scores.</p> <p>Summarise abundance of the species within the bottom quartile of species-specific residuals from the regression of brain mass against body mass.</p> <p>Summarise abundance of the species within the top quartile of the species body mass.</p>	

brains. The presence of numerous stones within fields positively related to the abundance of the most specialised species.

All the investigated variables related negatively and significantly to the year effect (Table 4; Supplementary material, Fig. A3). The temporal change was most pronounced for the Biomass and SR. All trait-based community indices were generally less sensitive to the field characteristics than the abundance of species within the top quartile of the respective trait.

#### 4. Discussion

##### 4.1. Relationships between community taxonomic richness and trait-based indices

Both taxonomic indices strongly intercorrelated across all fields: species-richness communities thus including also more of the species regarded vulnerable across Europe. Over the whole range of fields, the trait-based community indices of relevance to community sensitivity to

change positively related to community taxonomic richness, albeit mostly weakly. Local communities with more species included heavy species (high biomass). Such species usually occur at low densities and are registered sporadically (e.g., *Circus* spp., *Numenius arquata*) and tend to be at the top of the food chain (communities tend to have high CTI). Species-rich communities tended to be also more specialised and have lower brain profiles. Positive correlations between trophic and specialisation profiles most probably relate to several *Accipitridae* species and waders (e.g. *Circus* spp., the common snipe *Gallinago gallinago*, *N. arquata*) that are highly specialised in the region. Only two species high on the trophic score are characterised by low brain residuals (*N. arquata* and the whimbrel *N. phaeopus*), and the indices correlate most likely due to co-occurrence of common species with mid-range scores. Mostly weak positive correlations between species richness and trait-based metrics indicate that these metrics capture complementary information on the responses of communities to field types, i.e. anthropogenic impact.

**Table 4**

Statistical relationships among the studied the trait-based and taxonomic indices of bird communities, as well as abundances of individuals in top quartile of the respective functional traits, in an agricultural landscape in Northwest Russia (Pearson correlation coefficients and significance levels of the highest estimates from three study years). CSI – community specialisation index for the boreal zone; CTI – community trophic index; CBI – community brain index; SPEC – Species of European Conservation Concern (number of). Most specialised – top quartile of the specialisation score, Top of food chain – top quartile of the trophic score, Smallest brains – bottom quartile of the residuals for brain mass against body mass, and Heaviest – top quartile of the body mass. Correlations stronger than 0.3 are in bold. n = 230.

	Species richness	SPEC	Biomass	SCI	CTI	CBI	Most specialised	Top of food chain	Smallest brain
SPEC	<b>0.851<sup>***</sup></b>								
Biomass	<b>0.609<sup>***</sup></b>	<b>0.582<sup>***</sup></b>							
CSI	0.157 <sup>*</sup>	0.169 <sup>*</sup>	-0.25 <sup>**</sup>						
CTI	0.202 <sup>*</sup>	0.157 <sup>*</sup>	0.161 <sup>*</sup>	0.244 <sup>*</sup>					
CBI	0.215 <sup>*</sup>	0.1	-0.089	0.213 <sup>*</sup>	0.239 <sup>*</sup>				
Most specialised	<b>0.838<sup>**</sup></b>	<b>0.726<sup>**</sup></b>	<b>0.436<sup>**</sup></b>	0.286 <sup>**</sup>	0.198 <sup>**</sup>	0.204 <sup>**</sup>			
Top food chain	<b>0.762<sup>**</sup></b>	<b>0.692<sup>**</sup></b>	<b>0.937<sup>**</sup></b>	-0.014 <sup>*</sup>	0.189 <sup>**</sup>	0.184 <sup>**</sup>	<b>0.661<sup>**</sup></b>		
Smallest brain	<b>0.783<sup>**</sup></b>	<b>0.736<sup>**</sup></b>	<b>0.58<sup>**</sup></b>	0.049	0.05	-0.258 <sup>**</sup>	<b>0.731<sup>**</sup></b>	<b>0.788<sup>**</sup></b>	
Heaviest	<b>0.449<sup>**</sup></b>	<b>0.344<sup>**</sup></b>	<b>0.95<sup>**</sup></b>	<b>-0.306<sup>**</sup></b>	0.14 <sup>*</sup>	0.192 <sup>**</sup>	<b>0.296<sup>**</sup></b>	<b>0.844<sup>**</sup></b>	<b>0.414<sup>**</sup></b>

\*  $p < .05$ .\*\*  $p < .01$ .\*\*\*  $p < .001$ .**Table 5**

Parameter estimates from glmmPQL models relating the avian community taxonomic and functional composition to the field type, occurrence of non-cropped elements and year. CSI – community specialisation index for the boreal zone, CTI – community trophic index, CBI – community brain index, Biomass – community biomass. Abundance of individuals in top quartile of the respective functional traits: specialisation in the boreal zone (most specialised), place in the food chain (top of food chain), lowest brain mass residuals (smallest brains) and body mass (heaviest).

	CSI	CTI	CBI	Biomass	Species richness	Most specialised	Top of food chain	Smallest brain	Heaviest brain
Intercept	3.56 <sup>***</sup>	2.69 <sup>***</sup>	-0.30	4365.5 <sup>(*)</sup>	8.91 <sup>***</sup>	13.05 <sup>***</sup>	32.87 <sup>***</sup>	14.83 <sup>***</sup>	0.99
Field type									
Arable <sup>a</sup>	-0.86 <sup>***</sup>	-0.30 <sup>(*)</sup>	-0.02	-4146.6 <sup>*</sup>	-4.7 <sup>***</sup>	-8.69 <sup>***</sup>	-23.4 <sup>***</sup>	-10.87 <sup>***</sup>	-2.15
Grassland <sup>a</sup>	-0.17	-0.04	-0.02	-2598.4	-2.01 <sup>**</sup>	-4.22 <sup>***</sup>	-9.77 <sup>*</sup>	-3.14	-1.56
Pasture <sup>a</sup>	-0.55 <sup>*</sup>	-0.13	-0.05	4779.1 <sup>*</sup>	-1.10	-6.47 <sup>**</sup>	12.80 <sup>*</sup>	Feb-76	8.00 <sup>**</sup>
Ditches									
no ditches <sup>b</sup>	-0.05	0.19	0.06	-2483.2 <sup>(*)</sup>	-2.68 <sup>***</sup>	-4.19 <sup>***</sup>	-12.72 <sup>**</sup>	-4.02 <sup>*</sup>	-1.52
around the field <sup>b</sup>	0.02	0.28 <sup>*</sup>	0.06	-2919.7 <sup>*</sup>	-3.14 <sup>***</sup>	-4.45 <sup>***</sup>	-15.28 <sup>***</sup>	-5.17 <sup>*</sup>	-1.94
Bushes									
no bushes <sup>c</sup>	-0.14	-0.19	0.04	4149.8 <sup>*</sup>	-0.50	Jan-15	7.06 <sup>*</sup>	-4.39 <sup>(*)</sup>	6.51 <sup>*</sup>
only along ditches									
or by stone heaps <sup>c</sup>	-0.15	-0.18	-0.07	4371.0 <sup>*</sup>	-0.66	3.66 <sup>*</sup>	11-Dec	-7.40 <sup>*</sup>	6.31 <sup>*</sup>
Stones									
no stones <sup>d</sup>	0.06	0.13	0.09	-421.9	-1.66	-2.71 <sup>*</sup>	-5.19	-2.56	-0.78
a few stones <sup>d</sup>	0.03	0	-0.06	173.4	-0.85	-1.83	-3.24	-1.80	0.06
Year									
2010 <sup>e</sup>	-0.03	-0.02	-0.00	-447.5	-0.08	-0.72 <sup>*</sup>	-3.15 <sup>*</sup>	-2.48 <sup>***</sup>	-0.48
2011 <sup>e</sup>	-0.45 <sup>***</sup>	-0.22 <sup>***</sup>	-0.12 <sup>***</sup>	-3330.7 <sup>***</sup>	-3.11 <sup>***</sup>	-5.79 <sup>***</sup>	-17.7 <sup>***</sup>	-11.27 <sup>***</sup>	-3.53
Autocovariate	-0.01	-0.40	-0.68	0.58 <sup>**</sup>	0.64 <sup>***</sup>	0.64 <sup>***</sup>	0.70 <sup>***</sup>	0.60 <sup>***</sup>	0.27

(\*)  $p < .1$ .\*  $p < .05$ .\*\*  $p < .01$ .\*\*\*  $p < .001$ .<sup>a</sup> Compared with abandoned field.<sup>b</sup> Compared with ditches within the field.<sup>c</sup> Compared with bushes within field area.<sup>d</sup> Compared with numerous stones in the field.<sup>e</sup> Compared with 2008.

A generally congruent patterns, both in terms of positive correlations among all fields and in profiles of field types, differ from those described in the agricultural landscapes of France, where the avian community taxonomic richness and its specialisation were negatively correlated at both regional and national scales (Filippi-Codaccioni et al., 2010). There could be three reasons for this. Firstly, agricultural

land use in the region, and especially that of grasslands, is still extensive in comparison with that of North and Western Europe. An extensively managed system with numerous non-cropped elements and fallow land, as is the case here, may render more diversity and stability of resources, so that the species-rich community is composed of both generalists and specialists, and relatively more specialist species thanks to

a fuller niche partitioning in productive systems (Belmaker et al., 2012). Secondly, it is species highly specialised to arable cropping (Alaudidae, the corn bunting (*Miliaria calandra*)) that render a high specialisation profile to otherwise species-poor communities of arable fields. Most such species are missing from the boreal zone, and therefore arable fields are both relatively poor in species and do not support regionally specialised communities. Finally, it is plausible that a mismatch results from focusing at a more restricted set of species chosen as “farmland” in studies from France (20 species) than here.

#### 4.2. Patterns in taxonomic and trait-based metrics of field types

Positive correlations among some of the community metrics across the whole landscape most probably relate to the gradient from the least to the most disturbed field types: from low taxonomic and functional trait-based profiles of the arable field to generally high ones for abandoned fields. Species typical of arable fields tend to be seed-eating birds (i.e. low trophic level) (Pellissier et al., 2013); hence arable crop-dominated agricultural landscapes is dominated by assemblages with low trophic level profile (Mouysset et al., 2012). Under the intensive disturbance of arable cropping, only a few specialist species might survive due to their particular adaptations to such conditions, so a very species-poor community may be highly specialised (Filippi-Codaccioni et al., 2010; Teillard et al., 2015). In the boreal region, however, the pool of species with adaptations to open steppe-like environments is limited as compared to Central Europe (Filippi-Codaccioni et al., 2010) or the Mediterranean (Guerrero et al., 2011). Species with the highest specialisation scores in the boreal region are most numerous or exclusive in grasslands (e.g. *Circus* spp., the common quail (*Coturnix coturnix*), the corn crane (*Crex crex*), and *G. gallinago*), and thus favoured by more stable conditions in such habitats than those provided on arable fields. Low abundances of species from all sensitive groups in arable fields, even under moderately intensive production, indicate that such species seldom occupy arable fields or do so at relatively low densities in the boreal region (including such arable specialists as the Eurasian skylark (*Alauda arvensis*) and the northern lapwing (*Vanellus vanellus*)). The most important contribution of arable fields to a wider regional bird diversity may reside with their use as staging grounds by northern populations of geese and wader species (Herzon et al., 2014).

Community specialisation of abandoned fields was also high: some of the species most specialised for the boreal zone – *C. crex*, the whinchat (*Saxicola rubetra*), *G. gallinago*, common grasshopper warbler (*Locustella naevia*) – frequent them. However, in cultivated grasslands the abundances of most specialised birds and those high in the trophic chain were lower by about a third than in abandoned fields: high levels of the respective functional trait-based profiles on cultivated grasslands were thus determined mostly by numerous species with moderate specialisation or trophic position values (i.e. below the top 25%).

Our previous work in the region demonstrated that the taxonomic diversity of birds during the breeding season is at its highest in pastures followed by abandoned fields (Herzon et al., 2014). The only trait-based descriptor of high value in pastures was community biomass: double that of abandoned fields. Positive functions of pasturing livestock for birds are well described: supply of nutrients, abundant decomposer invertebrates, more resources for insectivorous bird species, i.e. higher trophic level (Vickery et al., 2001). Under relatively extensive pasture management in the region, considerable energy resources may remain available to birds as opposed to regularly reseeded pastures under heavy grazing pressure (ibid.). The abundance of the most specialised birds in pastures was about half of that in abandoned fields: abundant species typical of pastures (e.g. the rook (*Corvus frugilegus*), western jackdaw (*Corvus monedula*), the common starling (*Sturnus vulgaris*)) are not most specialised in the region.

Our results thus corroborate evidence for the importance of fields withdrawn from cultivation (also as set-asides or fallows; e.g. the meta-analysis by van Buskirk and Willi, 2004), but also for the regionally specialised species and top-consumer bird species. Teillard et al. (2015), using community functional trait-based profiles similar to the ones here, demonstrated that with even small levels of intensification, the agricultural habitat becomes unsuitable for specialised grassland species. Sustaining intentional presence of some fallowed fields within a productive agricultural landscape has been attempted in several countries with environmental following under national agri-environmental programmes (Toivonen et al., 2015) and currently across the whole European Union as ecological focus areas (Pe'er et al., 2016). Without political instruments, the value of the abandoned fields in a study region is short-lived.

#### 4.3. Role of the non-cropped elements

Some high vertical elements (such as hedges) and non-cropped patches (such as woodlots) are known to deter specialised farmland species of birds (Bas et al., 2009). Such elements are rare in the study region while several specialised species in the region (e.g. the red-backed shrike (*Lanius collurio*), northern wheatear (*Oenanthe oenanthe*), grey partridge (*Perdix perdix*), *L. tetrix*) are associated with fine-scale structures and microhabitats in fields, such as ditches and bushes here. In the high rainfall and rapid succession conditions of the boreal zone, drainage ditches with associated bushes and trees may mimic a natural habitat for specialist boreal species, allowing them to colonise farmland (Herzon and Helenius, 2008), which may explain the significant positive effect of ditches within fields on the abundances of the most specialised species. Therefore, at field level in the region, uncultivated habitats support community specialisation unlike in Chiron et al. (2010) and Filippi-Codaccioni et al. (2010) at landscape level in France.

#### 4.4. Implications for conservation

Focusing on functional trait-based community composition, such as specialisation and trophic level, was shown to be valuable for refining conservation targets and understanding underlying community changes at larger scales and involving several community types (e.g. Le Viol et al., 2012; Teillard et al., 2015; Dross et al., 2017). Community weighted mean indices are useful in synthesizing information on community composition and community changes. However, such metrics are not sufficiently accurate for identifying individual fields of potential conservation value: a high community weighted mean index may be driven by abundant species with moderately high species-specific values, not the most sensitive to change. Interpretation of results based on such indices may be supported by a parallel modelling of the top quartile values.

Applied to our study system, the trait-based indices indicated reasons for field types having varied conservation value. Expanding arable production or intensification of grassland management will likely not only result in the loss of species (Herzon et al., 2014) but also communities becoming less specialised, having lower standing crop biomass and lower trophic profile. Characteristics associated with high abundance of species groups sensitive to change – abandoned fields, pastures and ditches – are also vulnerable to increases in agricultural production (Stoate et al., 2009). In the study region, a combined output of cereals and legumes increased by 34% during 2010–2015 (Federal State Statistics Service, 2016). Some of it was driven by recultivation of abandoned fields, which may also be responsible for a temporal decline in the community descriptors. Schierhorn et al. (2014) proposed that primarily improving yields of existing croplands rather than recultiva-



tion of abandoned cropland is environmentally justified for European Russia. However, sustainability in the country is still viewed almost entirely through a prism of socio-economics with limited attention given to conservation of some key resources (such as soil fertility) in the country's strategic documents (summarised in Griewald et al., 2017).

## 5. Conclusions

Generally congruent patterns among the field types and in respect of presence of ditches in both taxonomic and trait-based descriptors indicate that accounting for the number of bird species regarded farmland seems to be sufficient to rapidly assess importance of field types and field structure for community sensitivity to change in the agricultural landscape of the study region, at least under current levels of production. Species richness remains a simple communication tool for policy and public alike and using it for a group of species known to extensively exploit farmland may be justified in providing an 'early warning' system in this agriculturally important region facing further intensification. For example, the role of abandoned but not yet overgrown fields as refuge for sensitive species is fully supported by functional trait-based community profiles.

A relatively weak congruence between taxonomic and trait-based indices highlights complementarity of using indices for understanding the underlying mechanisms of community changes. It would be instructive to investigate the context-dependent nature of the patterns between taxonomic and functional diversity of relevance to conservation across the range of both biogeographical zones and land-use intensities to test (cf Guerrero et al., 2011). The use of trait-based community analysis has been rapidly expanding and should not be neglected in regional studies.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.agee.2018.01.024>.

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