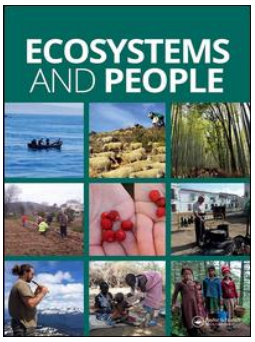

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Biodiversity modelling in practice - predicting bird and woody plant species richness on farmlands

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ABSTRACT

In light of decreasing species richness on farmland and an increasing awareness of biodiversity issues among customers and food companies, concepts and models to evaluate and enhance farmland biodiversity are greatly needed. It is important that the models are easy to apply as they have to be utilized by practitioners such as farmers and their consultants. In this study, simple but valid predictors were identified to rapidly assess the species richness of birds and woody plants in hedgerows, an important farmland landscape element. Hedgerows were sampled in seven agricultural landscapes throughout Germany. By means of automatic model selection procedures, linear regression models were estimated to predict bird and woody plant species richness. Cross validation procedures were carried out in order to visualize model selection uncertainty and estimate the prediction error. Due to a rather high prediction error, the model for plants can only be recommended for use when field work is not feasible. The model for birds, however, explained 70.8% of the variance in species numbers. It may help farmers, food companies and nature conservation agencies to rapidly evaluate bird species richness in hedgerows on farmland and to identify potentials and appropriate measures for enhancing it.

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1. Introduction

Halting the decline of biodiversity is a pivotal task for society. Within this objective, agriculture is a crucial sector for conservation actions. As indicated by the Secretariat of the Convention on Biological Diversity (2014), 70% of the projected loss of terrestrial biodiversity is associated with drivers linked to agriculture.

In the course of agricultural intensification, particularly since 1950, farmland biodiversity has increasingly declined (Stoate et al. 2001; Benton et al. 2002). Population declines on farmland have been observed e.g. for birds (Donald et al. 2001, 2006; Gregory et al. 2004), butterflies (Brereton et al. 2011), and the arable flora (Geiger et al. 2010; Storkey et al. 2012; Deckers et al. 2004a). For farmland birds, impacts of agricultural intensification include a shortage of nesting places, e.g. on fields as a result of denser and more homogeneous swards (Wilson et al. 2005), and a shortage of food supply due to decreases in both weed cover and insect populations caused by an intensive use of herbicides and insecticides (Benton et al. 2002; Boatman et al. 2004). For arable flora, the use of highly effective herbicides, increases in fertilizer use, together with shortened periods between harvest and stubble cultivation and decreased fallow periods, have each contributed to the decrease in species numbers (Albrecht 1995; Beckmann et al. 2019). Agricultural intensification is also associated with a loss of semi-natural habitats and a removal of hedgerows (Newton 2004).

It is obvious that farmers play an important role in maintaining and enhancing biodiversity on farmland. This importance is also reflected in agri-environmental programs, e.g. supporting the development of hedgerows on farmland. It is not only farmers and nature conservation agencies that are becoming increasingly aware of and interested in biodiversity on farmland but also food companies and their customers (Kempa 2013). Already, some companies encourage their suppliers to engage in biodiversity measures on their land (Gottwald and Stein-Bachinger 2015). For such purposes, methods and benchmarks are needed so that this biodiversity engagement and its success can be evaluated. As direct biodiversity mapping on farms is expensive, in terms of time and money, there is a demand for easy-to-use indicator-based models that allow food companies and authorities to time-effectively evaluate how farms perform in terms of biodiversity (Kempa and von Haaren 2012; Kempa 2013; Kramer et al. 2017). Here, we present such models for the prediction of bird species richness and woody plant species richness in hedgerows, based on simple but valid predictors.

Hedgerows are important habitats for birds in the agricultural landscape, providing food, shelter, and nesting places. Their bird species richness has frequently been found to be positively influenced by variables such as the length (Zwölfer et al. 1984; Barkow 2001; Batáry et al. 2010), width (Hinsley et al. 1999), and the volume of

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Supplemental data for this article can be accessed here

a hedgerow (Osborne 1984; Hinsley and Bellamy 2000; Walker et al. 2005) as well as – to a certain extent – by its height (Parish et al. 1994; MacDonald and Johnson 1995). Further important variables positively influencing bird species richness or abundance include the number of woody plant species (MacDonald and Johnson 1995; Hinsley and Bellamy 2000) and the presence or abundance of trees, tree holes, and dead trees (Osborne 1984; Parish et al. 1994; Hinsley and Bellamy 2000; Walker et al. 2005) in a hedgerow. Thorny shrubs, especially hawthorn and blackthorn, have shown to be preferred nesting habitats and to positively influence bird abundance (Zwölfer et al. 1984; Schröder 1988; Walker et al. 2005). Additional variables that are likely to be important for bird species richness or abundance include the age or cutting rotation of a hedge, as there is a tendency towards higher bird abundances in medium aged or older hedges (Zwölfer et al. 1984; Schröder 1988; Barkow 2001). Other studies have detected positive influences on bird species richness or abundance of the width or presence of verges and ditches (Parish et al. 1994; see also MacDonald and Johnson 1995); when there are two parallel and adjacent hedgerows (Walker et al. 2005); if pastures are the adjacent land use (Zwölfer et al. 1984; Parish et al. 1994; Walker et al. 2005); and when there is a high hedge density in the surroundings (O'Connor 1984; Zwölfer et al. 1984). In several studies, organic farming (e.g. Chamberlain et al. 1999; Fischer et al. 2001; Bengtsson et al. 2005) and a high landscape heterogeneity (Balent and Courtiade 1992; Kretschmer et al. 1995; Billeter et al. 2008) have been associated with an increase in bird species richness or abundance on farmland.

For plants, the surrounding environmental conditions of a hedge are considered to be among the most important factors influencing species richness. For instance, sandy soil types (De Blois et al. 2002; Aude et al. 2003; Deckers et al. 2004a) and soils with a low nutrient availability (Aude et al. 2003) particularly have positive effects on species richness. Hedge structure is also considered to be very important. Plant species numbers were, for instance, found to increase with an increase in hedge width (Forman and Baudry 1984; Boutin and Jobin 1998; Boutin et al. 2002; De Blois et al. 2002; Le Coeur et al. 2002; Deckers et al. 2004a); the length of a hedge (Deckers et al. 2004a; Orlowski and Nowak 2005; Ernoult and Alard 2011); the presence of trees (Moonen and Marshall 2001; Deckers et al. 2004a); the presence of shrubs (Moonen and Marshall 2001; Boutin et al. 2002; Le Coeur et al. 2002; Deckers et al. 2004a); the presence of a bank (Moonen and Marshall 2001; Aude et al. 2003; Deckers et al. 2004a); and the presence of a ditch (Forman and Baudry 1984; Deckers et al. 2004a). Species richness also depends on the history of a hedge. The history of a hedge can be depicted by its origin, as planted hedges are supposed to have low whereas spontaneous hedges and remnant hedges have high species numbers (Forman and Baudry 1984; Boutin et al. 2002; Deckers et al. 2004a). The age of a hedge is also pertinent, as older hedges are supposed to have higher species numbers (Aude et al. 2003). Additional influential factors include adjacent habitats or land cover (French and Cummins 2001; Moonen and Marshall 2001; De Blois et al. 2002; Le Coeur et al. 2002; Aude et al. 2004; Deckers et al. 2004a; Campagne et al. 2006). For instance, both the type of farming in adjacent fields – with organic farming having a positive effect (Forman and Baudry 1984; Aude et al. 2003, 2004; Boutin et al. 2008) – and margin strips that can buffer any negative effects from adjacent habitats (Jobin et al. 1997; Moonen and Marshall 2001) are factors which influence species richness positively. In terms of hedge management, a cutting rotation of no or numerous cuttings has shown to have negative effects (De Blois et al. 2002; Huwer and Wittig 2013). Certain types of maintenance measures, such as pollarding or coppicing (Moonen and Marshall 2001; Croxton et al. 2004; Deckers et al. 2004a) have proven to have positive effects. Finally, landscape variables such as a high landscape heterogeneity (Deckers et al. 2004a, 2004b) and a high amount of source habitats (hedges, woodland, forest) in the surroundings (Boots 2001; Boutin et al. 2002, 2008; Deckers et al. 2004a; Ernoult and Alard 2011) influence the plant species richness found in a hedge positively.

For developing models to evaluate species richness in hedgerows, we have to consider not only how certain characteristics of hedgerows influence species richness in these landscape elements, but also how such models have to be designed to comply with the needs of the addressees of the models such as the farmers and food suppliers. This requires that models are based on readily available data, that the number of indicators be as low as possible and that the software, the models are embedded in, is easy to use (Kempa and von Haaren 2012; Kempa 2013; Kramer et al. 2017).

Besides designing the models to be feasible, they also need to produce results which are legitimate, credible and useful for decision makers (salient) (van Oudenhoven et al. 2018). More explicitly, and relevant for our context and application, (i) the models should base evaluations on legitimate criteria and standards, that are deduced from national and international legislation. This is the only form in which morals are transferred to standards and can be accepted in principle by everybody (von Haaren and Lovett 2019). In addition to this basic evaluation, morals e.g. of food producers and consumers may add voluntary objectives but these have to be distinguished from the criteria set by the law. (ii) Credibility of modelling results is mainly achieved by empirically and statistically testing the model (e.g. Heink and Kowarik 2010) and defining the remaining uncertainties (transparency). (iii) Salience, the usefulness for the addressees, includes e.g. scalability and transferability because the results of different farms should be comparable and monitored (von Haaren et al. 2019).

The models presented here for the evaluation of the species richness of birds and woody plants in hedgerows, comply with the afore mentioned modeling criteria and complement and broaden previously published models assessing the value of field margins for butterfly and plant species richness (Sybertz et al. 2017) and the value of field habitats for plant species richness (Bredemeier et al. 2015). They provide the farmer with an additional component to gain a whole-farm perspective on biodiversity enhancement potentials. To ensure credibility and transparency, we estimated linear regression models based on predictors supported by scientific literature (van Oudenhoven et al. 2018), evaluated the stability of the models' parameters and estimated their prediction error.

In this study, we focus on species richness as a measure for farmland biodiversity as it is a common and frequently used criterion for evaluating the conservation value of agricultural habitats (Bredemeier et al. 2015). Richness of farmland species well represents the biodiversity of these ecosystems, including rare and endangered species (Bredemeier et al. 2015), and thus complies with the principles of European and German legislation on biodiversity conservation (legitimacy).

2. Materials and methods

2.1. Identification of variables important for birds and plants

European studies about birds in hedgerows and on farmland, as well as woody plant species in hedgerows, were thoroughly investigated using Web of Science and – to identify grey literature such as research reports and dissertations – Google Scholar. The search terms used were: (hedgerow OR hedge) AND (birds OR [plant AND 'species number']) as well as the German equivalents. The search was implemented on titles, keywords and abstracts (Web of Science) or on articles (Google Scholar), respectively. The papers and reports were screened for suitability and all variables were identified which, based on empirical evidence, were specified in at least one reference as influencing bird species richness and/or abundance or woody plant species richness either positively or negatively. Such variables were compiled and, if similar, assigned to variable groups (Tables 1 and 2).

2.2. Study sites

Hedgerows in seven different agricultural landscapes typical to Germany were studied, ranging from the north to the south of Germany. In each study site, i.e. each agricultural landscape, hedgerows associated with fields farmed by one single farm were sampled (Figure 1). Two of these farms were managed conventionally, while the other five farms were organically managed. The total size of the fields per farm ranged from 58 ha to 700 ha. The fields and consequently the associated hedgerows, however, were usually spatially dispersed within the surveyed landscapes, with an average minimum distance of 392 m (nearest hedgerow) and a maximum average distance of 4.9 km (furthest hedgerow) between the sampled hedgerows per study site (for a detailed description of the agricultural landscapes and farms see Table S1, Supplementary material). All hedgerows were bordered on at least one side by arable land and had a minimum length of 10 m.

2.3. Bird and plant surveys

For the bird survey, six to ten randomly chosen hedgerows were investigated per study site. For the survey of woody plant species, ten hedgerows were examined per

Table 1. Variables influencing bird species richness and/or abundance in hedgerows and similar habitats.

Variable (group)	Sources
Length	Barkow 2001; Batáry et al. 2010; Chamberlain and Wilson 2000; Heusinger 1984; Voigtländer et al. 2001
Width	Barkow 2001; Chamberlain and Wilson 2000; Hinsley et al. 1999; Sparks et al. 1996; Voigtländer et al. 2001
Height	Chamberlain and Wilson 2000; Green et al. 1994; Hinsley et al. 1999; MacDonald and Johnson 1995; Sparks et al. 1996; Parish et al. 1994
Volume	Hinsley and Bellamy 2000; Sparks et al. 1996; Osborne 1984; Parish et al. 1994; Walker et al. 2005
Age/cutting rotation	Barkow 2001; Schröder 1988; Zwölfer et al. 1984
No. of woody species	Hinsley and Bellamy 2000; MacDonald and Johnson 1995; Osborne 1984
Dominant shrub species/presence of thorny shrubs	Schröder 1988; Walker et al. 2005; Zwölfer et al. 1984
Trees (hedgerow trees, tree layer, tree holes, dead wood)	Green et al. 1994; Hinsley and Bellamy 2000; MacDonald and Johnson 1995; O'Connor 1984; Osborne 1984; Parish et al. 1994; Sparks et al. 1996
Width of herbaceous margin	Parish et al. 1994
Ditch presence	MacDonald and Johnson 1995; Parish et al. 1994
Position of nearest hedge	Walker et al. 2005
Hedge density in surroundings	Fuller et al. 2001; O'Connor 1984; Zwölfer et al. 1984
Adjacent land use	Barkow 2001; Fuller et al. 2001; MacDonald and Johnson 1995; Parish et al. 1994; Walker et al. 2005; Zwölfer et al. 1984
Adjacent farming method	Batáry et al. 2010; Belfrage et al. 2005*; Chamberlain et al. 1999*; Christensen et al. 1996*; Fischer et al. 2001*; Smith et al. 2010*
Heterogeneity of surrounding landscape	Balent and Courtiade 1992*; Batáry et al. 2010; Billeter et al. 2008*; Kretschmer et al. 1995*

source referring to farmland in general and not explicitly to hedgerows

Table 2. Variables influencing the number of woody plant species in hedgerows.

Variable group	Variable	Source
History	Origin	Boutin et al. 2002; Deckers et al. 2004a; Forman and Baudry 1984
	Age	Aude et al. 2003
Hedge structure	Width	Boutin and Jobin 1998; Boutin et al. 2002; De Blois et al. 2002; Deckers et al. 2004a; Forman and Baudry 1984; Le Coeur et al. 2002
	Length	Deckers et al. 2004a; Ernoult and Alard 2011; Orlowski and Nowak 2005
	Presence of trees	Deckers et al. 2004a; Moonen and Marshall 2001
	Presence of shrubs	Boutin et al. 2002; Deckers et al. 2004a; Le Coeur et al. 2002; Moonen and Marshall 2001
	Presence of a bank	Aude et al. 2003; Deckers et al. 2004a; Moonen and Marshall 2001
	Presence of a ditch	Deckers et al. 2004a; Forman and Baudry 1984
Environmental conditions	Soil type	Aude et al. 2003; De Blois et al. 2002; Deckers et al. 2004a
	Nutrients	Aude et al. 2003
Management	Cutting rotation	De Blois et al. 2002; Huwer and Wittig 2013
	Type of maintenance measures	Croxton et al. 2004; Deckers et al. 2004a; Moonen and Marshall 2001
Adjacent habitats	Adjacent land cover	Aude et al. 2004; Campagne et al. 2006; De Blois et al. 2002; Deckers et al. 2004a; French and Cummins 2001; Le Coeur et al. 2002; Moonen and Marshall 2001
	Farm type/management of adjacent fields	Aude et al. 2004, 2003; Boutin et al. 2008; Forman and Baudry 1984
	Existence of margin strips	Jobin et al. 1997; Moonen and Marshall 2001
Landscape variables	Landscape heterogeneity	Deckers et al. 2004a, 2004b
	Amount of source habitats in the surroundings	Boots 2001; Boutin et al. 2002; Boutin et al. 2008; Deckers et al. 2004a; Ernoult and Alard 2011

study site. The sample for birds consists of 59 hedges, whereas the sample for plants consists of 70 hedges.

For the bird survey, each study site was visited five times between March and July 2014, during favorable weather conditions, i.e. no rain and no strong wind (Südbeck et al. 2005). All surveys were carried out by the same person. The surveys took place in the early morning hours, starting from dawn to 11 am. All species that were visually and/or acoustically observed in or directly above the hedgerow were noted. Thus, not only breeding birds but all birds using the hedgerow were included in the survey. The observer walked the entire length of each hedgerow, on one side, twice per visit at a slow pace. For every hedgerow, a list of all observed species was composed. Nomenclature was used according to Svensson et al. (2011). Red List species were identified following Südbeck et al. (2007).

Woody plant species were surveyed from May to July, 2015, and each hedge was surveyed once. The entire length of the hedge was circled on foot by the observer and all woody plant species were noted. Thus, the census line covered the entire length and width of each hedge. Nomenclature followed Buttler and Hand (2008). Red List species were identified following Ludwig and Schnittler (1996).

2.4. Environmental variables

Based on the variables that influence bird species richness and/or abundance in hedgerows (Table 1), and those that affect the number of woody plant species (Table 2), as identified by the literature review, we defined environmental variables which are easy to obtain, either via aerial photographs, GIS maps, farmer interviews or by means of a brief on-site inspection. For each hedgerow, 30 environmental variables were recorded (Table 3); 7 common variables, 12 relevant only for birds and 11 relevant only for plants. We measured total length and mean width and estimated the mean height of a hedgerow. Regarding management, we recorded in the field and interviewed the farmers on how often a hedge is cut; the type of maintenance measure (e.g. pollarded); and whether it was cut partially or totally. The number of woody species in the hedgerow was estimated and it was noted whether thorny shrubs were present and whether blackthorn and/or hawthorn were dominant species. Furthermore, we recorded if the hedgerow had a tree layer or if single hedgerow trees were present; if the hedgerow had a shrub layer; if the hedgerow was located upon a bank or if it was adjacent to

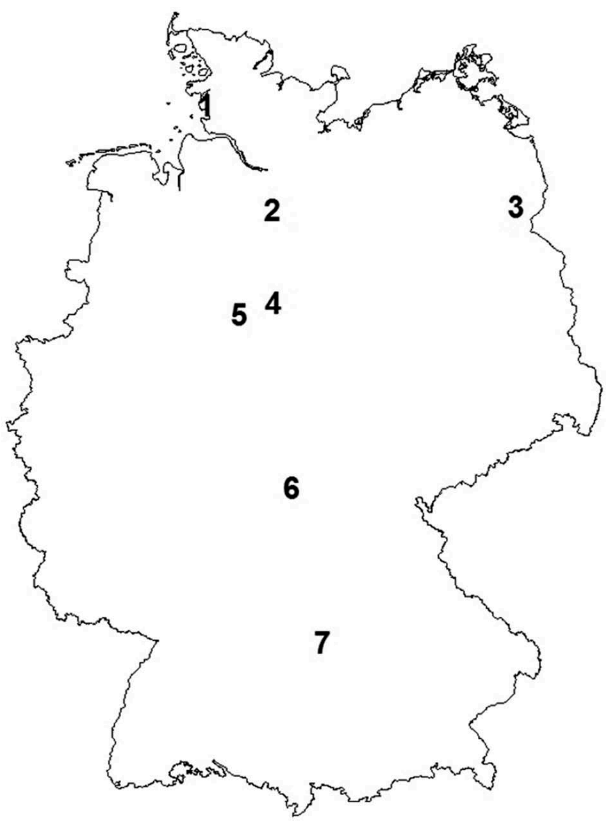

Figure 1. Study sites in Germany. 1: Friedrichsgabekoog, 2: Bispingen, 3: Angermünde, 4: Algermissen, 5: Hameln, 6: Ostheim vor der Rhön, 7: Megesheim.

a ditch. The width of the herbaceous margin bordering the hedge was measured on both sides. Additionally, the adjacent land use and the adjacent land cover were recorded for both sides of the hedgerow. We noted if another hedge or a similar wooden structure was parallel and adjacent to the hedgerow in question and estimated, from aerial pictures and expert-based reference pictures (Table 3), the surrounding hedge density. Regarding the management of adjacent fields, we interviewed the farmers regarding whether the management type of these fields was organic or conventional. We estimated the age and determined the origin of each hedgerow based on field surveys and on information provided by the farmers. For environmental conditions, we recorded the soil type and the nutrient availability. Finally, we estimated the landscape heterogeneity and the amount of source habitats in the surroundings using aerial pictures and expert-based reference pictures (Table 3).

2.5. Statistical analysis

The total number of bird species which were observed during the five surveys (TOTAL_BIRD) and the number of woody plant species per hedgerow (TOTAL_PLANT) were used as response variables.

The recorded environmental variables were screened for their suitability as explanatory variables. If a category had too low a number of cases ($n < 5$) it was excluded or combined with another category (Table S2, Supplementary material). For the remaining metric explanatory variables, as well as for the response variables, it was investigated whether it was necessary to transform variables with extreme data points, skewed distributions or non-linear relationships between the explanatory and response variable. For this purpose, we visually examined histograms to identify variables with skewed distributions and extreme data points. Additionally, we used scatter plots to check whether the response and explanatory variables were non-linear related. Based on this preliminary analysis, LENGTH, WIDTH, AGE, and HEIGHT were transformed by taking the natural logarithm (ln) in order to smooth the distribution for further analysis. TOTAL_BIRD, MARGWIDTH1, and MARGWIDTH2 as well as MARGIN_STRIP_WIDTH were transformed with $\ln(x + 1)$ as there were a number of zero-values present. No extreme data points were excluded in any of the variables.

All explanatory variables were checked for correlations by calculating Spearman's rank coefficient between numeric variables; Kruskal-Wallis effect size between numeric and categorical variables; and Pearson's contingency coefficient between categorical variables. Spearman's rank correlation was subsequently used to examine dependencies between quantitative explanatory variables and response variables, and Kruskal-Wallis test was used to test effects of categorical variables on response variables.

We computed multiple linear regression models with automatic linear modelling procedures in IBM SPSS Statistics 23 in order to predict species numbers for the response variables with forward stepwise selection and with the corrected Akaike Information Criterion (AICc) as a criterion for the entry of variables. No automated data preparation was carried out during automatic linear modelling procedures. Nominal and ordinal variables were 0/1-dummy coded to avoid the assumption of a linear increase or decrease in dependence of the ordinal levels.

The models were cross-validated in order to visualize the models' selection uncertainty, and to estimate the prediction error for future study sites in a way that includes both model selection uncertainty (Hastie et al. 2009) and between-site variability. We reran the models' selection procedure seven times, each time with a reduced data set such that the data of each study site was left out once. Hence, the automatic model selection was rerun on the remaining six study sites and the resulting model selection uncertainty was displayed by means of tables. Hereafter, we predicted the species numbers for each study site using the model based on the reduced data set consisting of the remaining six study sites. The predicted species numbers were then combined for all study sites and depicted and correlated with the observed species numbers in order to visualize the prediction error.

2.6. Interactions with stakeholders

The whole research process was accompanied by discussions with several food producers, whom were consulted on a regular basis and interviews of the managers of the test farms regarding the usefulness of the results and their demands on the models (salience). Regarding these aspects, the modelling procedures were not only necessary for validly predicting species numbers but also for reducing the large number of possible predicators to the most important ones in order to increase feasibility of the model application.

3. Results

3.1. Birds and plants in hedgerows

Altogether, 61 bird species were found in hedgerows on the seven investigated study sites (Table S3, Supplementary material) with the common whitethroat (*Sylvia communis*), yellowhammer (Emberiza citrinella), and common blackbird (*Turdus merula*) being the most frequently recorded ones.

The total number of bird species per study site ranges from 21 (farm 4, Algermissen) to 36 (farm 3, Angermünde). Altogether, 14 Red List species were identified. The total number of bird species and the number of endangered bird species showed highly significant correlations ($r_S = 0.596$***).

For woody plants, a total of 101 species were recorded (Table S4, Supplementary material), of

Table 3. Variables recorded for each hedgerow.

Variable (Abbreviation)	Definition; Categories/Units	Data source
Response variables		
Bird species number per hedgerow (TOTAL_BIRD)	Total number of species observed in a hedgerow	Field survey
Woody plant species number per hedgerow (TOTAL_PLANT)	Total number of woody plant species detected in a hedgerow	Field survey
Common explanatory variables: birds and plants		
Length (LENGTH)	Total length of a hedgerow (m)	Measurement in Arc GIS on the basis of aerial pictures (LGB, 2014; LGLN, 2014; LVerGeo SH, 2014; LVG, 2014)
Width (WIDTH)	Mean width of a hedge at a representative section (m)	Measurement in Arc GIS on the basis of aerial pictures (LGB, 2014; LGLN, 2014; LVerGeo SH, 2014; LVG, 2014)
Cutting rotation (CUTROT)	Recording of the cutting rotation of the hedgerow; 0 = no cutting; 1 = cutting every 1–5 years; 2 = cutting every 6–20 years; 3 = cutting > 20 years	Field survey; interview with farmers
Trees (TREES)	Recording whether a tree layer or single hedgerow tree is present; 0 = no; 1 = yes	Field survey
Ditch adjacent (DITCH)	Recording whether a ditch is adjacent to the hedgerow; 0 = no ditch adjacent; 1 = ditch adjacent (dry); 2 = ditch adjacent (wet)	Field survey
Management of adjacent fields (MANAGFIELD)	Recording how fields adjacent to the hedge are managed; 1 = all adjacent fields conventionally managed; 2 = one adjacent field conventionally and one organically managed; 3 = all adjacent fields organically managed	Interview with farmers
Landscape heterogeneity (LANDHET)	Estimation of the amount of near-natural habitats in a 1 km radius of the farm with reference images; 1 = low landscape heterogeneity; 2 = average landscape heterogeneity; 3 = high landscape heterogeneity	Own estimation based on aerial pictures (LGB, 2014; LGLN, 2014; LVerGeo SH, 2014; LVG, 2014) in ArcGIS and reference images of landscapes with low, average and high landscape heterogeneity (Sybertz et al. 2017)
Explanatory variables: birds only		
Height (HEIGTH)	Estimation of the mean height of the hedge (m)	Field survey
Partial cutting (PARTCUT)	Recording whether the hedgerow is partially cut when managed; 0 = no; 1 = yes	Field survey; interview with farmers
Number of woody species (NOWOOD)	Estimation of the number of woody species in a hedgerow; 1 = 1–3 species; 2 = 4–9 species; 3 = ≥ 10 species	Field survey
Thorny shrubs (THORNSHRUB)	Recording whether thorny shrubs are present; 0 = no; 1 = yes	Field survey
Dominant shrubs (DOMSHRUB)	Recording whether blackthorn (*Prunus spinosa*) and/or hawthorn (*Crataegus monogyna*) are dominant shrubs; 0 = no; 1 = yes	Field survey
Tree holes, dead wood (HOLES)	Recording whether tree holes or dead wood suitable for tree holes are present; 0 = no; 1 = yes	Field survey
Width of herbaceous margin 1 (MARGWIDTH1)	Width of adjacent herbaceous margin (first side) in decimeters	Field survey
Width of herbaceous margin 2 (MARGWIDTH2)	Width of adjacent herbaceous margin (second side) in decimeters	Field survey
Position of nearest hedge (POSHEDGE)	Recording whether another hedgerow or similar wooden structure is parallel and adjacent; 0 = no; 1 = yes	Aerial pictures (LGB, 2014; LGLN, 2014; LVerGeo SH, 2014; LVG, 2014); field survey
Hedge density in surroundings (HEDGEDENS)	Estimation of hedge density in a 1 km radius of the farm with reference images; 1 = low hedge density in surroundings; 2 = average hedge density in surroundings; 3 = high hedge density in surroundings	Own estimation based on aerial pictures (LGB, 2014; LGLN, 2014; LVerGeo SH, 2014; LVG, 2014) in ArcGIS and expert-based reference images (Fig. S1, Fig. S2, Fig. S3 in Supplementary material)
Adjacent Land use 1 (LANDUSE1)	Recording of the land use adjacent to the hedgerow (first side); 1 = fields, intensive meadows/pastures, roads, man-made habitats adjacent; 2 = extensive meadows/ pastures, gardens, semi-natural habitats adjacent	Field survey
Adjacent Land use 2 (LANDUSE2)	Recording of the land use adjacent to the hedgerow (second side); 1 = fields, intensive meadows/pastures, roads, man-made habitats adjacent; 2 = extensive meadows/pastures, gardens, semi-natural habitats adjacent	Field survey
Explanatory variables: plants only		
Origin of a hedge (ORIGIN)	Description of the origin of a hedge; 1 = planted; 2 = combination of planted and spontaneous; 3 = spontaneous or remnant	Field survey
Age of the site (AGE)	Minimum age of a hedge in years	Field survey; interview with farmers
Presence of shrubs (SHRUB)	Recording whether the hedgerow has a shrub layer; 0 = no; 1 = yes	Field survey

(*Continued*)

Table 3. (Continued).

Variable (Abbreviation)	Definition; Categories/Units	Data source
Presence of a bank (BANK)	Recording whether there is a bank at the bottom of the hedgerow; 0 = no; 1 = yes	Field survey
Soil type (SOIL_TYPE)	Predominant soil type of a hedge; 0 = loam, clay, silt; 1 = sand	Digital soil maps (LBEG, 2016; LBGR, 2016a; LDBV, 2015; LLUR, 2015; LLUR, 2016)
Nutrient availability (NUTRIENTS)	Soil value of the hedgerow's site according to soil maps	Digital soil maps (LBEG, 2016; LBGR, 2016b; LDBV, 2015; LLUR, 2016)
Type of maintenance measures (MAINTENANCE_TYPE)	Recording of the type of maintenance measures; 1 = none; 2 = maintained with hedge trimmer; 3 = pollarded; 4 = cut almost to the ground; 5 = combination of the former	Field survey; interview with farmers
Adjacent land cover (ADJ_LAND_COVER)	Recording of the type of land cover adjacent to a hedge; 1 = arable fields on both sides; 2 = arable field on one side; 3 = grassland on both sides; 4 = grassland on one side (other side not arable field)	Field survey; aerial pictures (LGB, 2014; LGLN, 2014; LVerGeo SH, 2014; LVG, 2014)
Existence of margin strips (MARGIN_STRIP)	Recording whether there are margin strips or grasslands adjacent to a hedge. Field margins are taken into account, too; 1 = margin strip <3m or not existent; 2 = one side margin strip ≥3m or grassland; 3 = both sides margin strip ≥3m or grasslands	Field survey
Width of margin strips (MARGIN_STRIP_WIDTH)	Width of margin strips towards agricultural area in decimeters. If agricultural areas are bordering both sides, the longer distance is taken into account.	Field survey
Amount of source habitat in the surroundings (SOURCE_HABITATS)	Estimation of the amount of source habitats (hedges, shrubbery, woods) in a 1 km radius of the farm; 1 = low (<10%); 2 = medium (10% – 30%); 3 = high (>30%)	Own estimation on the basis of aerial pictures (LGB, 2014; LGLN, 2014; LVerGeo SH, 2014; LVG, 2014) in ArcGIS

which only one was endangered. Species numbers range from a minimum of 34 on farm 7 (Megesheim) to a maximum of 47 different species on farm 1 (Friedrichsgabekoog).

3.2. Correlations between explanatory variables

A number of significant correlations were found between the explanatory variables (Table S5, Table S6, Supplementary material).

Within the variables relevant for birds, strong correlations were found between the height of a hedge and the presence of trees, tree holes, and the number of woody species. The presence of trees showed a highly significant correlation with the presence of tree holes and the number of woody species. Landscape heterogeneity was found to be highly correlated with the presence of ditches and the hedge density in the surroundings. Furthermore, the analysis showed that longer hedgerows tended to be wider and higher and had a higher number of woody species (Table S5, Supplementary material).

Within the relevant variables for plants, high correlations were found between landscape heterogeneity and adjacent ditches; management of adjacent fields and adjacent land cover; origin of a hedge and existence of margin strips; as well as length and width. The amount of source habitats was found to be highly correlated with the presence of ditches, soil type, nutrient availability, and landscape heterogeneity. Furthermore, the type of maintenance measures showed a highly significant correlation with the presence of shrubs and the cutting rotation (Table S6, Supplementary material).

3.3. Correlations between response and explanatory variables

The total number of bird species showed highly significant positive correlations with the length, width, and height of a hedgerow (Table 4). Moreover, bird species numbers were strongly positively correlated with the numbers of woody species in hedgerows. The presence of trees in the hedgerow and tree holes both showed strong positive correlations with bird species numbers.

The number of woody plant species was strongly positively correlated with the origin as well as the width and length of a hedge, the presence of trees, and the soil type. To a lesser extent, woody plant species numbers were positively correlated with the management of adjacent fields, the existence of a margin strip, the width of margin strips, and source habitats in the surroundings (Table 5). A negative correlation was detected with nutrient availability.

3.4. Model selection through stepwise linear regressions

By means of automatic modelling procedures, two models were selected and estimated; one to predict the number of bird species in a hedgerow and one to predict the number of woody plant species. The model for bird species numbers selected length, width, the presence of tree holes, low numbers of woody plant species, and the width of the herbaceous margin between the hedgerow and adjacent field as predictors. These variables collectively explained 70.8% of the variance in the number of bird species (Table 6).

The model for woody plant species numbers selected the length of a hedge, the presence of trees, and the origin of a hedge (categories: planted; combination of planted and spontaneous) as the best predictors. The model using these variables explained a total of 61.1% of the variance in the response variable (Table 7).

The inspection of the VIF values in both models did not reveal any problem of multicollinearity (Table S7, Table S8, Supplementary material), which is generally the case for a VIF value >3 (Zuur et al. 2009).

3.5. Cross validation

During cross validation, the length of a hedgerow proved to be the most important and stable predictor in the bird models as it was selected by all rerun models. This was followed by the width of a hedgerow and low numbers of woody species (as a predictor negatively influencing species richness), which were selected by six out of seven rerun models. Additionally, variables that were selected by either three or four of the rerun models were the presence of tree holes, the width of the herbaceous margin between the hedge and adjacent field and the presence of thorny shrubs (Table 8).

For woody plant species, the cross validation procedure showed the length of the hedge to be the most important variable in the linear regression. Its relevance was confirmed in each of the rerun models with the data of one study site excluded. The presence of a tree layer and the planted origin of the hedgerow were of minor importance. Each of these variables showed significant effects in four models. The category describing the origin of a hedgerow as partly planted and partly spontaneous showed a significant result in one rerun model (Table 9).

The predicted values of the cross validation procedures using each model, and for each study site, showed significant positive correlations with the observed species numbers (for birds: $r_S = 0.777^{***}$; for woody plant species: $r_s = 0.453^{***}$) (Figure 2). Figure 2(a,b) illustrate the prediction error of the linear regression models including the model's selection uncertainty.

The root mean squared error of prediction (RMSE), calculated according to Faraway (2005), is 3.52 species for birds and 8.47 species for woody plants.

Table 4. Results for Spearman's rank correlations and Kruskal-Wallis tests between response and explanatory variables for birds. For variable abbreviations see Table 3.

Variable	TOTAL_BIRD
LENGTH*	0.798
WIDTH*	0.656
HEIGHT*	0.576
MARGWIDTH1*	0.171
MARGWIDTH2*	0.077
NOWOOD+	0.494
TREES+	0.275
HOLES+	0.175
LANDHET+	0.053
HEDGEDENS+	0.052
DITCH+	0.046
DOMSHRUB+	0.037
MANAGFIELD+	−0.031
PARTCUT+	0.029
THORNSHRUB+	0.027
POSHEDGE+	0.026
LANDUSE2+	−0.009
CUTROT+	−0.002

*Numeric variable: Marginal association is shown by Spearman's rank correlation coefficient; +Categorical variable: Marginal association is shown by effect size (H-k + 1)/(n-k) related to test statistic of Kruskal-Wallis-Test H, with n observations in k categories.

Table 5. Results for Spearman's rank correlations and Kruskal-Wallis tests between response and explanatory variables for woody plants. For variable abbreviations see Table 3.

Variable	TOTAL_PLANT
LENGTH*	0.687
NUTRIENTS*	−0.436
WIDTH*	0.419
MARGIN_STRIP_WIDTH*	0.280
AGE*	−0.013
TREES+	0.376
ORIGIN+	0.241
SOIL_TYPE+	0.203
SOURCE_HABITATS+	0.133
MANAGFIELD+	0.105
MARGIN_STRIP+	0.078
LANDHET+	0.046
MAINTENANCE_TYPE+	−0.038
DITCH+	−0.015
ADJ_LAND_COVER+	−0.014
CUTROT+	−0.011

*Numeric variable: Marginal association is shown by Spearman's rank correlation coefficient; +Categorical variable: Marginal association is shown by effect size (H-k + 1)/(n-k) related to test statistic of Kruskal-Wallis-Test H, with n observations in k categories.

Table 6. Results of the automatic linear modelling for bird species numbers in hedgerows (R^2 = 0.733; adj. R^2 = 0.708; $p < 0.001$). For variable abbreviations see Table 3.

Variable	Coefficient	SE	t	Sig.
Intercept	0.184	0.258	0.716	ns
ln(LENGTH)	0.319	0.060	5.313	***
ln(WIDTH)	0.319	0.116	2.745	**
Dummy_NOWOOD (Cat. = 1)	−0.388	0.120	−3.230	**
Dummy_HOLES (Cat. = 1)	0.197	0.096	2.041	*
ln(MARGWIDTH1 + 1)	0.184	0.114	1.620	ns

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns: not significant.

Table 7. Results of the automatic linear modelling for woody plant species numbers in hedgerows (R^2 = 0.633; adj. R^2 = 0.611; $p < 0.001$). For variable abbreviations see Table 3.

Variable	Coefficient	SE	t	Sig.
Intercept	−8.040	2.574	−3.124	**
ln(LENGTH)	3.896	0.645	6.036	***
Dummy_ORIGIN (Cat. = 1)	4.461	1.424	3.133	**
Dummy_TREES (Cat. = 1)	3.925	1.310	2.996	**
Dummy_ORIGIN (Cat. = 2)	2.385	1.286	1.855	ns

** $p < 0.01$; *** $p < 0.001$; ns: not significant.

4. Discussion

4.1. Predictors of bird species numbers in hedgerows

Five easy-to-obtain variables were identified in order to predict bird species numbers in hedgerows: length, width, the presence of tree holes, the width of the herbaceous margin between the hedge and adjacent fields, and a low number of woody species. While low numbers of woody species were found to have a negative influence on bird species numbers, the other variables were identified as having a positive influence. Most of these variables are frequently mentioned in other studies on bird species richness in hedgerows, especially length and width (Barkow 2001; Batáry et al. 2010; Heusinger 1984; Voigtländer et al. 2001, for hedgerows in different parts of Germany; Chamberlain and Wilson 2000; Hinsley et al. 1999; Sparks et al. 1996, for hedgerows in different parts of the UK). In their review, Hinsley and Bellamy (2000) stated that the two most important variables for the species richness of breeding birds in hedgerows in the UK are their size (i.e. height, width and volume) and the presence and/or abundance of trees. In our study, we found tree holes to be a better predictor of bird species richness than trees but found both variables to be highly correlated. The importance of the number of woody species in a hedgerow has also been demonstrated by several studies in which bird-rich hedges were found to be rich in woody species (e.g. in the UK: MacDonald and Johnson 1995; Hinsley and Bellamy 2000). MacDonald and Johnson (1995) argue that hedgerows which are rich in shrubs might provide more food in terms of insects and a greater structural diversity. The width of the herbaceous margin adjacent to a hedge is less frequently mentioned. Parish et al. (1994) found a relationship between bird species richness and verge dimensions of hedgerows in eastern England. Birrer et al. (2007) detected a positive influence of the width of the herbaceous margin on the density and distribution of hedgerow indicator species in Switzerland.

In this study, bird species richness was not found to be positively influenced by the landscape heterogeneity of the surroundings or the farming method adopted in the fields adjacent to a hedgerow. These are, however, two variables which have been frequently found to positively influence birds on farmland (e.g. Batáry et al. 2010; Fischer et al. 2001; Kretschmer et al. 1995, for different parts of Germany; Smith et al. 2010, for southern Sweden; Billeter et al. 2008, in a pan-European study). Furthermore, we could not detect an effect of land uses adjacent to the hedgerow. This might be an intrinsic problem of our sample which is dominated by hedgerows bordering arable fields. Most of the identified variables have proven to be stable during cross validation, i.e. they have proven to be consistently included with similar estimates across most or all submodels in cross validation. However, some variables can easily be substituted by others, e.g. the influence of tree holes could also be captured by the presence of trees or the height of a hedgerow. The latter is interesting, regarding the automatization of biodiversity evaluation procedures, as the presence of trees can be estimated by means of aerial pictures while tree holes can only be detected in the field.

In addition to the above discussed variables, and according to the results of the cross-validation, the presence of thorny shrubs proved to be important for the prediction of bird species numbers in three of the examined study sites. In order to acknowledge the importance of this variable for biodiversity evaluation in certain parts of Germany, we provide an alternative version of the model, which includes the presence of thorny shrubs, in the appendix (S9 and Table S11, Supplementary material).

4.2. Predictors of woody plant species numbers in hedgerows

The model to predict the species richness of woody plants contained the variables: the length of a hedge, the existence of a tree layer, and the origin of a hedge. The relevance of the length of a hedge has been proven in several former studies across Europe (e.g. Deckers et al. 2004a, in Flanders, Belgium; Ernoult and Alard 2011, in northern France; Orlowski and Nowak 2005, in south-western Poland). The impact of the existence of trees or a tree layer has only been previously illustrated in a few research papers, for instance by Deckers et al. (2004a) for hedgerows in Flanders, Belgium, and by Moonen and Marshall (2001) for hedgerows in southern England. The positive effect of the hedgerow being planted on species richness is surprising, but is probably related to our specific data set, as some hedgerows (e.g. on farm 3, Angermünde) were planted with the aim to be species-rich. In the reviewed literature spontaneous or remnant hedges are named as the most species-rich (Forman and Baudry 1984; Boutin et al. 2002; Deckers et al. 2004a). The 'origin of a hedge' variable not only showed an overall effect that differed from the literature findings, but it also showed contrary directions of effects in different study sites (S9, Supplementary material). Evidently, the use of this variable in a model spanning multiple sites seems problematic. Therefore, we provide an alternative version of the model, that excludes the origin variable, in the appendix (S9 and Table S10, Supplementary material).

Contrary to what we expected regarding the literature research, neither the management or landscape

Table 8. Parameter estimates for AICc selected variables models, fitted to the complete data set (first row) and to subsets in the cross-validation procedure for bird species numbers (Study sites: FRI = Friedrichsgabekoog; BIS = Bispingen; ANG = Angermünde; ALG = Algermissen; HAM = Hameln; OST = Ostheim vor der Rhön; MEG = Megesheim). Values in the columns are parameter estimates in the respective model. 1, 2 and 3 stars indicate the significance of the parameter estimate at level 0.05, 0.01, and 0.001, respectively. The last column gives the adjusted R^2 of each rows model fit. For variable abbreviations see Table 3.

Response variable	Intercept a	ln(LENGTH)	ln(WIDTH)	ln(HEIGHT)	Dummy_ CUTROT (Cat. = 0)	Dummy_ NOWOOD (Cat. = 1)	Dummy_ HOLES (Cat. = 1)	ln (MARGWIDTH1 + 1)	ln (MARGWIDTH2 + 1)	Dummy_ THORN SHRUB (Cat. = 1)	Dummy_ MANAGFIELD (Cat. = 3)	Dummy_ POSHEDGE (Cat. = 1)	Dummy_ TREES (Cat. = 1)	Dummy_ LANDHET (Cat. = 3)	adj. R^2
ln (TOTAL_BIRD + 1)	0.184	0.319***	0.319**			−0.388**	0.197*	0.184							0.708
ln (TOTAL_BIRD + 1) except FRI	0.122	0.337***	0.283**			−0.267*	0.187*	0.234*							0.727
ln (TOTAL_BIRD + 1) except BIS	−0.159	0.319***	0.344**			−0.316*		0.195		0.347					0.706
ln (TOTAL_BIRD + 1) except HAM	0.175	0.350***	0.383**			−0.471**					−0.199	0.181			0.728
ln (TOTAL_BIRD + 1) except ALG	−0.723	0.337***	0.260*	0.235	0.282*					0.406*		0.186	0.293*	−0.301*	0.776
ln (TOTAL_BIRD + 1) except ANG	0.300	0.288***	0.313*			−0.398**	0.288*	0.192							0.681
ln (TOTAL_BIRD + 1) except MEG	0.376	0.306***	0.214			−0.539***	0.259*		0.209						0.730
ln (TOTAL_BIRD + 1) except OST	0.133	0.370***			0.315**	−0.290	0.268*			0.416*					0.730

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

variables nor the soil type and nutrient availability variables showed any significant results in the linear regression analyses. For soil type and nutrient availability this is surprising as both variables yielded a significant coefficient in the linear regression analysis with the response variable. This effect might be due to a strong relationship of both nutrient availability and soil type with length in our data set (Table S6, Supplementary material). As length was selected as one of the model's predictors it could have masked the influence of these two variables. Nevertheless, the strong relationship between these variables is not commonly observed.

Due to the above discussed shortcomings and a rather low explanatory value of the model for woody plants, a field estimation by the farmer or consultant for the number of woody plants in a hedgerow is probably a better option for biodiversity evaluation. However, a refined version of the model could be beneficial in biodiversity evaluation processes that are increasingly being automated and in instances where field work cannot be carried out.

4.3. Recommendations for farmers, food companies and nature conservation agencies

We aimed at developing scientifically valid but simple and easy-to-use models in order to ensure usability among practitioners. To achieve this, we tested and discussed the models in workshops with the food companies and farmers participating in this study. The value of all the variables can be recovered from existing data or collected from a brief on-site inspection by the farmer or a farm consultant, within a reasonably short amount of time and with only little ecological knowledge. In the future, with better automatic satellite interpretation, the provision of information for running such models will be made even easier. The regression models can be used, for instance, in the form of a calculator for public use on the internet or be applied in the context of GIS-based management software for farmers (e.g. the open-source software MANUELA; von Haaren et al. 2008).

It is not only the status quo on contract farms that can be evaluated but also the potential for enhancing species numbers, through nature conservation measures. This potential can be estimated and simulated by changing the values of the variables, the farmer wants to influence through nature conservation measures, in the models. Small hedgerows and small adjacent herbaceous margins, for instance, can be extended and species poor hedgerows can be enriched by planting indigenous woody plant species, including thorny shrubs. For tree holes, single hedgerow trees can be established in the long term while, in the short term, nesting boxes can be put up where appropriate. These aspects are also important for the planting of new hedgerows.

Table 9. Parameter estimates for AICc selected variables models, fitted to the complete data set (first row) and to subsets in the cross-validation procedure for woody plant species numbers (Study sites: FRI = Friedrichsgabekoog; BIS = Bispingen; ANG = Angermünde; ALG = Algermissen; HAM = Hameln; OST = Ostheim vor der Rhön; MEG = Megesheim). Values in the columns are parameter estimates in the respective model. 1, 2 and 3 stars indicate the significance of the parameter estimate at level 0.05, 0.01, and 0.001, respectively. The last column gives the adjusted R^2 of each rows model fit. For variable abbreviations see Table 3.

Response variable	Intercept a	Dummy_ORIGIN (Cat. = 1)	Dummy_ORIGIN (Cat. = 2)	ln(AGE)	ln (WIDTH)	ln (LENGTH)	Dummy_TREES (Cat. = 1)	Dummy_DITCH (Cat. = 2 + 3)	Dummy_CUTROT (Cat. = 3)	Dummy_CUTROT (Cat. = 4)
TOTAL_PLANT	−8.040	4.461**	2.385			3.896***	3.925**			
TOTAL_PLANT except FRI	−18.551		2.333*			5.509***	2.127			2.832*
TOTAL_PLANT except BIS	−13.984	4.088**	2.739			4.106***	2.257		−2.728*	
TOTAL_PLANT except HAM	−5.286	4.120**				3.621***	4.158**	−3.236*		3.134
TOTAL_PLANT except ALG	−28.611			2.855*	3.918*	3.965***	3.568**			3.462*
TOTAL_PLANT except ANG	−4.584					3.068***	4.744***			
TOTAL_PLANT except MEG	−30.211	6.790**		5.013**		4.009***			−2.052	
TOTAL_PLANT except OST	−10.035	5.188**	2.207			4.053***	4.089**			

Response variable	Dummy_MAINTENANCE_TYPE (Cat. = 3)	Dummy_MAINTENANCE_TYPE (Cat. = 4)	Dummy_ADJ_ LAND_ COVER (Cat. = 1)	Dummy_ADJ_ LAND_ COVER (Cat. = 4)	Dummy_MANAGFIELD (Cat. = 1)	Dummy_MANAGFIELD (Cat. = 3)	ln (MARGIN_ STRIP_ WIDTH +1)	Dummy_LAND HET (Cat. = 1)	Dummy_LAN DHET (Cat. = 3)	Dummy_SOURCE_HABITATS (Cat. = 3)	adj. R^2
TOTAL_PLANT											0.611
TOTAL_PLANT except FRI					4.456**	7.219***	1.540	3.962*		−1.625	0.802
TOTAL_PLANT except BIS	4.583*	2.834*			5.962**	3.889			3.723**		0.712
TOTAL_PLANT except HAM			−2.989*								0.626
TOTAL_PLANT except ALG					4.225*	8.454***		−5.441***			0.768
TOTAL_PLANT except ANG		1.951									0.495
TOTAL_PLANT except MEG		3.888**		−6.538	9.205***	5.566**			3.893*		0.707
TOTAL_PLANT except OST					2.055						0.643

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

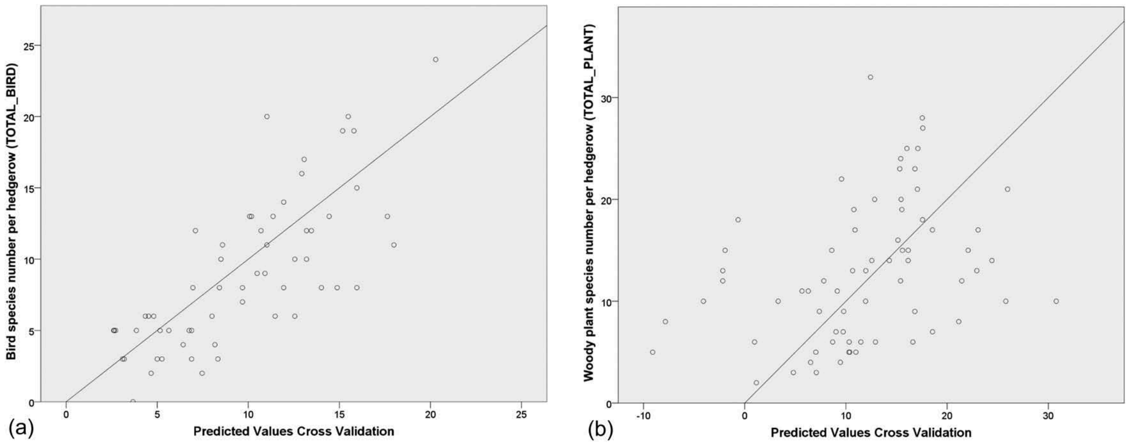

Figure 2. Comparison between observed values and values generated during cross validation for species numbers per hedgerow. (a) Bird species (TOTAL_BIRD; $r_S = 0.777^{***}$). (b) Woody plant species (TOTAL_PLANT; $r_s = 0.453^{***}$).

Food companies can encourage their contracted farmers to participate in such measures by offering them long-term contracts or financial incentives (Kempa 2013). However, subsidies are not necessarily the most important factor for a long-term motivation (Schenk et al. 2007; Ahnström et al. 2008; De Snoo et al. 2013). Instead, farmers' might be motivated if these measures contribute to a positive image of farming (Siebert et al. 2010) – an aspect that can also be integrated into the companies' marketing strategies. Farmers could be further motivated if comparisons between farms also include biodiversity aspects besides productivity and by encouraging them to learn from each other's experiences with regard to biodiversity issues (De Snoo et al. 2013). Both aspects can be fostered as parts of the corporate culture of a food company accompanied by result oriented agri-environmental measures. Important factors for acceptance are that measures can be adapted to meet farm-specific requirements (Ahnström et al. 2008) and that farmers feel that their local knowledge is appreciated (Harrison et al. 1998). As the models for hedgerows complement previously published models for field margins (Sybertz et al. 2017) and arable fields (Bredemeier et al. 2015), companies can offer their contracted farmers the choice between which measures to use or which landscape element focus best fits their farms. To make the right choices for the enhancement of biodiversity, the assistance of farm consultants provided by the companies or by nature conservation authorities can be beneficial. For farmers in landscapes characterized by open farmland, for example, a stronger focus on field habitats than on hedgerows might be more appropriate as there are also birds which need open farmland and avoid dense hedgerow networks and other wooden structures such as skylark (*Alauda arvensis*), lapwing (*Vanellus vanellus*) and corn bunting (*Emberiza calandra*) (Kretschmer et al. 1995; Hinsley and Bellamy 2000; Hoffmann and Greef 2003).

It is important to note that our model is designed to evaluate the alpha-diversity of a single hedgerow and not the beta-diversity of a complex of several hedgerows. Different species have, of course, different needs and thus there is no such thing as a perfect hedgerow which is suitable for all species (Arnold 1983; Hinsley and Bellamy 2000; Barkow 2001). Consequently, farmers should try to improve hedgerows in a variety of different ways, particularly those hedgerows with a low value according to the model results. In this way, farmers can establish a diversity of different types of hedges on their land (cf. Barkow 2001; Fuller et al. 2001).

Despite the importance of hedgerow length for predicting the number of bird species, we recommend the careful interpretation of its importance for nature conservation issues. With regard to the species-area relationship, we expected and found more species in longer hedgerows; however, shorter hedgerows usually have a higher territory density due to edge effects (Zwölfer et al. 1984; Barkow 2001). Zwölfer et al. (1984) therefore recommend the establishment of several shorter hedges within a close distance to each other instead of one long hedgerow.

For the remuneration of agri-environmental measures, companies and nature conservation agencies should be aware that the success of measures to improve the value of the hedgerows also depends on, e.g. the colonization potential of the surroundings (Buskirk Van and Willi 2004) and there may be delays of several years (Chamberlain et al. 2000). Nevertheless, the extension or improvement of a hedgerow or hedgerow network have the potential to better provide shelter, nesting places and food, increasing species richness in future years, and thus can be remunerated based on these expected future results.

Aside from the many advantages and potentials of modelling, the stakeholder discussion also clarified that a wide-spread application will depend on framing conditions such as the Common Agricultural Policy (CAP) and the market for agricultural products. Running a model is only attractive for farmers when their market access depends on it or if they can use it for several purposes. Applications could be driven by success oriented remuneration of environmental services, common demands of different food producers to whom they supply farm products, or a legal regulation demanding farm assessment and monitoring. None of these preconditions exist yet. The CAP would be a strong incentive, but more result or success orientation of subsidies is not yet foreseeable. Running a model as a GIS-based web application is not well accepted by farmers because of data issues. Taking into consideration these impediments, food companies plan to firstly implement an easy to use app, which will run without a GIS application and which can be based on the results presented in this paper.

5. Conclusions

Depicting environmental benefits provided by contract farmers is important for food companies, especially producers of organic food, in terms of marketing (Kempa 2013). Furthermore, the precise planning of agri-environmental measures, including the evaluation of their results, remains an unsolved issue for farmers and involved agencies.

The presented models – as well as the already published models for arable flora on fields (Bredemeier et al. 2015) and butterflies and plants on field margins (Sybertz et al. 2017) – are an important instrument for the rapid and transparent evaluation of environmental benefits and can serve as a tool for on-farm planning of agri-environmental measures. Together, they contribute to a whole-farm perspective for the evaluation of biodiversity status and enhancement potential for three important habitat types on agricultural land. However, for the evaluation of woody plant species richness, the estimation of the number of woody plants in the field might be a more reasonable option if feasible.

To facilitate a broad application of the models, we included a wide spectrum of geographic and agricultural variation within our data set and carefully cross-validated the models. However, the transferability of the results to regions that differ from those studied should be tested before application (for comparison see description of the study sites in Table S1, Supplementary material). Additionally, the models should not be used with values too distant from the data range used to estimate them (Table S13 and S14, Supplementary material). The inclusion of more data, especially from regions which are underrepresented in our data set and from more conventional farms, is desirable. Furthermore, as the *presence* of species is the most important but not the only relevant indicator, a possible future development of the models could be the inclusion of *abundance* data. Another area of future research is the modeling, not only of the alpha-diversity of single hedgerows but also of the beta-diversity of all hedgerows on a farm.

Beside species richness, the presence of endangered species is a major aspect of biodiversity conservation. For birds, correlations between the number of all species and the number of endangered species were positive and highly significant in our dataset. However, as none or only one endangered species was observed in the majority of hedgerows (Table S13, Supplementary material), examining the effect of different variables on endangered species was not possible and is subject to future research. For plants, investigating the relationship between species richness and the number of endangered species was not possible as there was only one endangered species recorded in one hedge (Table S14, Supplementary material). However, a relationship between the number of total plant species and endangered plant species is assumed for arable land (Bredemeier et al. 2015; c.f. Kolářová et al. 2013).

The developed models can be utilized by farmers and food companies as well as by conservation authorities running agri-environmental schemes. Based on the results, the potential and appropriate measures for enhancing biodiversity can be identified. The most important added value of the models is to enable a transparent comparison of farm performances in terms of biodiversity.

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