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Village modernization may contribute more to farmland bird declines than agricultural intensification

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Abstract

The central tenet of European farmland ecology is that agricultural intensification during the 20th century was largely responsible for dramatic declines in species abundances. However, during this time, human rural settlements were also undergoing radical changes through modernization, with undocumented biodiversity impacts in this important wildlife habitat. We performed the first ever large-scale study to disentangle the impact of these simultaneous processes on farmland bird diversity in 104 Polish villages. We show that modernized villages and their surrounding agricultural fields had 50–60% fewer birds than those in and around comparable older villages. The relative contribution of modernization versus agricultural intensification to predicted bird declines was 88% versus 12% for bird communities in villages and 56% versus 44% in surrounding croplands, with considerable variation among ecological species subgroups. These results challenge our current understanding of agricultural ecosystem ecology and how best to implement conservation measures costing billions of euros annually.

KEYWORDS
biodiversity, farmland birds, housing renovation, modern architecture, rural landscape, sustainable development, urbanization, village ecological values

1 | INTRODUCTION

Biodiversity declines in European farmlands continue despite the European Union (EU) spending €50 billion since 2007 to mitigate biodiversity effects of agricultural intensification (Gamero et al., 2017; PECBMS, 2018). Yet changes in the architecture and structure of rural settlements since the 1950s that cooccurred with agricultural intensification and resulted in the loss of village ecological values (Antrop, 2000, 2004) are rarely considered
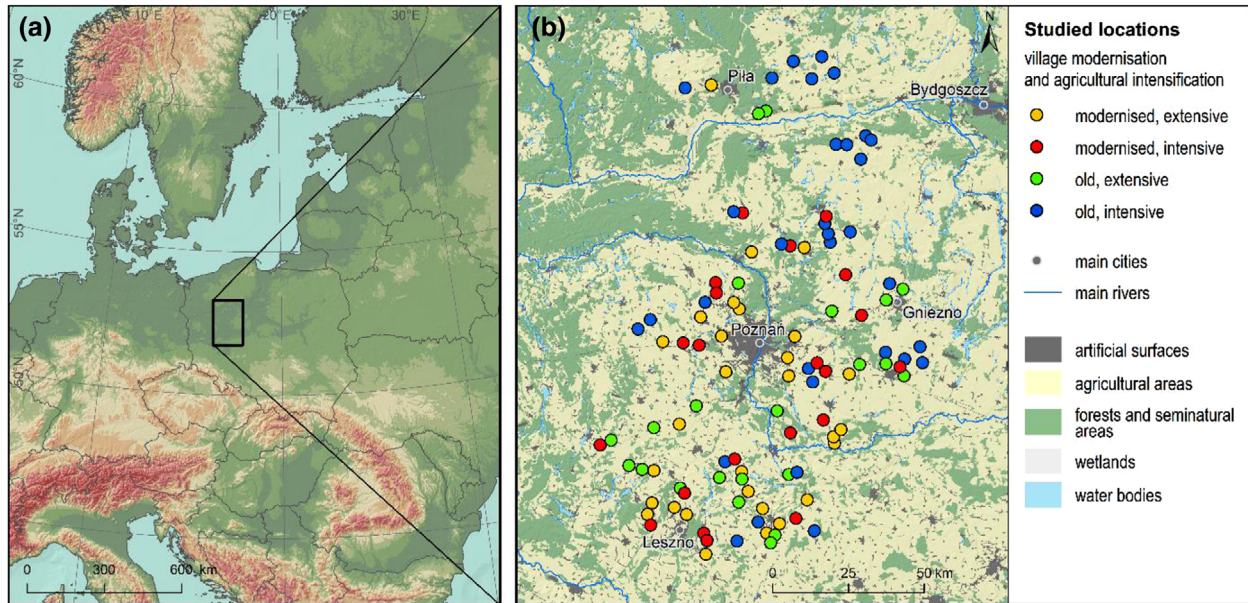
FIGURE 1 Study area and design: villages were selected in the main agricultural region in Poland (Wielkopolska; containing 4348 villages in total) and stratified with respect to distance to the nearest city (as villages located closer to a city tend to be more modernized compared to remote villages) and mean field size in surrounding landscape (as a proxy of agriculture intensification), so that the resulting selection contained villages (*n* = 104) in all combinations of modernization level and agriculture intensification in the surroundings

in this ecological and conservation framework (Driscoll et al., 2018). This is despite rural villages and farmsteads being a characteristic and widespread part of agricultural landscapes of Europe and many farmland bird species breed and forage in these environments (Hiron et al., 2013; Rosin et al., 2016; Šálek et al., 2018). Building renovation or replacement using modern building methods and styles removes nesting opportunities for a suite of species who rely on structures in old buildings for their long-term persistence (e.g., house sparrow *Passer domesticus*, tree sparrow *P. montanus*, barn swallow *Hirundo rustica*) (Rosin et al., 2020). The decline of family-based farmsteads in favor of big specialized farms, also substantially reduces biodiversity through reductions of food resource and nest site heterogeneity (Møller, 2001; Wretenberg et al., 2007). Considering that rural areas cover 44% of the EU and contain 30% of the human population (European Commission for Agriculture & Rural Development, 2018), it is astonishing that we know so little about the effects of rural settlement modernization on farmland biodiversity.

Agricultural intensification and modernization of farmsteads and villages had already occurred in much of western of Europe by the late 20th century (Antrop, 2000, 2004), but for central and eastern European countries this process largely began in the early 1990s after the fall of communism and continued after 2004 with their accession to the EU (Chmieliński & Karwat-Woźniak, 2015; Har-

tel et al., 2014; Mikulcak et al., 2013; Reif & Vermouzek, 2019; Sutcliffe et al., 2015). Thus, it is still possible in some European countries to study the emergence and relative impact of these two processes on farmland biodiversity. In this study, we focus on an agricultural region in central-western Poland (Wielkopolska) where villages are at different stages of modernization and located in landscapes with different levels of agricultural intensification (Figure 1). This allows us to investigate the relative contribution of the two large-scale structural changes in rural landscapes on farmland bird diversity, and how these processes interact. We designed a large-scale orthogonal study in order to independently link the modernization levels of 104 villages and levels of surrounding agricultural intensification to farmland bird abundance and richness in both village and cropland environments (Figure 2). To better understand the relationship between variation in these processes and the birds' ecology, we examined how local modernization and intensification variables (Table S1) are related to farmland bird abundances for four species groups: (1) all farmland birds, (2) birds associated with buildings (building nesters), (3) birds associated with noncrop habitats (noncrop nesters), and (4) open field nesting species (field nesters; Table 1). Findings from this study show that by only focusing on the cropland environment for farmland bird conservation we are likely ignoring important drivers of farmland biodiversity declines.
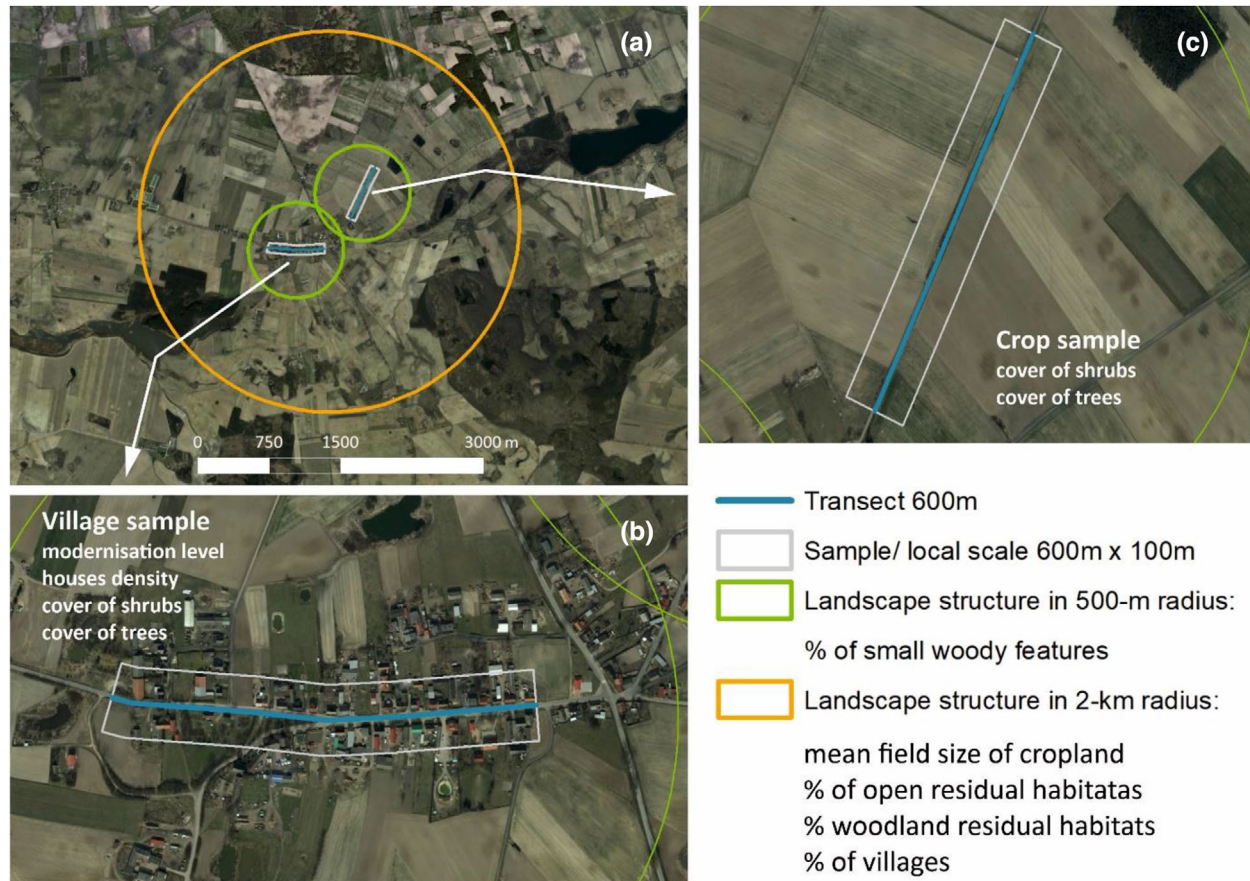
FIGURE 2 A study location (a) containing village (b) and adjacent crop (c) sample; birds were surveyed along transects (600-m long; blue line) with a buffer zone of 50 m on the right and left side of the transect (light grey lines) giving 6 ha of a sample area. Environmental variables were assessed at (1) local scale (within a sample area: share of new and renovated homesteads and houses density in a village, and % cover of shrubs and trees in village and crop samples); (2) landscape scale within 500-m radius from a center point of a transect (% cover of small woody features; green circles) and within 2-km radius from a centroid between village and crop transect (mean field size of cropland, % cover of open residual habitats, % cover of woodland residual habitats and % cover of villages; orange circle). Distance to the village from a crop sample was measured on the line between the center points of village and crop transects

2 | METHODS

2.1 | Study area and design

The study was conducted in a major agricultural region in central-western Poland, Wielkopolska, that contains 4348 villages in ~30,000 km². It is highly diverse in its level of rural development and modernization (Rosin et al., 2020) (Figure 1). Villages are defined as human settlements without city status, with a population size ranging from <10 to several thousand; these settlements are primarily composed of properties aggregated in rural landscapes. We selected 104 villages based on a random, partly stratified selection process (Rosin et al., 2020), satisfying the following criteria: (1) the village was compact and linear in structure, at least 600 m in length, with rural properties at both sides of the road (Figure 2); (2) surrounded by farmland. In

order to achieve orthogonality among the environmental variables of interest, (3) villages were stratified with respect to distance to closest city; (4) within each distance class from cities, we selected an equal number of villages surrounded by three main types of farmland based on mean field size: small, medium, and large fields (see Appendix A1). The minimum distance between adjacent studied villages was 5 km to ensure our sample units were discrete in terms of breeding bird communities.

2.2 | Bird surveys

We performed bird surveys during the 2017 breeding season (Rosin et al., 2020). Four experienced observers counted birds within 50 m along transects 600 m long (Figure 2; two visits/transect; for more details see

TABLE 1 Total abundance of farmland bird species recorded in the study village and crop environments. Species are classified as either building, noncrop or field nesting species (see details in Section 2)

	Village $N = 104$	Crop $N = 102$
Building nesters		
Passer domesticus	4922	54
Hirundo rustica	1352	202
Passer montanus	1138	202
Streptopelia decaocto	839	4
Phoenicurus ochruros	283	3
Delichon urbicum	258	1
Apus apus	197	7
Motacilla alba	132	42
Corvus monedula	76	2
Ciconia ciconia	27	5
Noncrop nesters		
Sturnus vulgaris	1407	357
Chloris chloris	318	17
Linaria cannabina	227	59
Carduelis carduelis	136	56
Columba palumbus	129	35
Serinus serinus	94	4
Turdus pilaris	92	17
Miliaria calandra	86	274
Sylvia communis	64	71
Emberiza citrinella	13	95
Acrocephalus palustris	11	24
Corvus cornix	9	8
Lanius collurio	2	33
Lanius excubitor	1	0
Buteo buteo	1	3
Corvus frugilegus	0	8
Emberiza hortulana	0	7
Saxicola rubetra	0	10
Curruca nisoria	0	2
Falco tinnunculus	2	1
Upupa epops	1	2
Field nesters		
Galerida cristata	55	37
Alauda arvensis	33	738
Motacilla flava	13	314
Oenanthe oenanthe	5	7
Anthus pratensis	1	4
Vanellus vanellus	1	10
Anthus campestris	0	1
Coturnix coturnix	0	6
Perdix perdix	0	9

Appendix A1). Transects were located in two types of environment, village ($n = 104$; along the main village road; Rosin et al., 2020) and adjacent field ($n = 104$; oriented perpendicularly to the village transect into the surrounding fields and >50 m from village boundaries; Figure 2; Appendix A1).

2.3 | Environmental characteristics

Variables describing the structure of study villages and crops and their surroundings were measured at two spatial scales: local (i.e., within 50 m of transect line) and landscape (i.e., within a 500-m radius from central point of a transect and 2-km radius from the centroid between village and crop transects; Figure 2).

Based on Rosin et al. (2020), we used share of new and renovated homesteads as a proxy of village modernization level (hereafter VM; Figure 2, Table S1). Number of properties in the sampling area (6 ha) was classified as housing density. Distance to the nearest village was calculated for crop transects based on the length between central points of village and crop transects. Local environmental characteristics complemented percentage cover of shrubs and trees (Figure 2, Table S1).

Factors describing the landscape around transects included (1) cover of small woody features measured within a 500-m radius (2) mean field size of cropland, (3) open residual habitat area (hereafter ORH), (4) woodland residual area (hereafter WRH), and (5) village area within 2-km radius (Figure 2, Table S1).

We described agricultural intensification (hereafter AI) using the following variables: cover of small woody features, open, and woodland RH and mean field size. These were previously shown to be important for farmland birds (Clough et al., 2020; Fahrig et al., 2015; Šálek et al., 2018).

2.4 | Species groups

We analyzed farmland bird species as a (1) singular group, and separately in three species-subsets based on differences in general breeding habitat (Hiron et al., 2015); (2) building nesting species that use built-up structures as nesting sites (10 species); (3) noncrop nesters requiring vertical noncrop habitats (mid-field trees or shrubs) during breeding (21 species); and (4) species nesting in open fields and avoiding vertical structures (9 species; Table 1). The selection of farmland species was according to the most well-cited studies of European farmland bird diversity and declines (Donald et al., 2001; Hiron et al., 2013, 2015; Wretenberg et al., 2007). In addition, we used a second set of selection groupings based on the European

index of common birds (PECBMS, 2018) using the same approach, so our results were valid with reference to the Farmland Bird Index (Table S4). For each species group we used the maximum value of bird number (abundance) observed during either visit (Rosin et al., 2020), with a similar approach used for analyzing species richness.

2.5 | Statistical analysis

We modeled the relationship between bird abundance and environmental variables (Figure 2, Table S1 and Appendix A2) separately for village ($n = 104$) and crop ($n = 102$) transects for the four farmland-associated bird species groups (8 models in total); and species richness and environmental variables for all farmland birds in both surveyed environments (2 models). All models shared most of the local and landscape explanatory variables (for list of predictors, see Table S1 and for specific model formulations, see Appendix A2).

We created a global model that included variables describing the level of village modernization (VM) and agricultural intensification (AI) factors for making predictions of the absolute and relative magnitude of the effects of VM versus AI. We also included a number of local and landscape variables in the models (Figure 2, Table S1, and Appendix A2) to control for factors that were likely important in determining species abundances (e.g., amount of shrubs and trees in villages or cover of villages in the surrounding landscape) but were not directly related to either VM or AI (Table S1). Because the impact of VM and AI could likely interact in determining local bird diversity, in all models we also included the interaction between level of modernization × cover of open residual habitats (ORH) and the interaction between level of modernization × mean field size (Table S1 and Appendix A2). All explanatory variables in these models were standardized ((variable − mean)/1 SD) to directly compare parameter estimates within models, and to improve model convergence. Field size area was log-transformed to normalize its distribution, and thus all parameters describing this variable and interactions including this variable relate to ln(field size). Variance inflation factor for continuous variables indicated low levels of collinearity (highest VIF = 2.26 was found for field size; see also Tables S7 and S8). There was no evidence of spatial autocorrelation (Moran I coefficient for model residuals < 0.35).

Fitted models were used to extract predictions of bird abundances under different scenarios of VM and AI, based on the range of these explanatory variables observed within this study (Appendix A2). Regression models and estimates of posterior distributions were performed using a Bayesian framework in JAGS (Plummer, 2004) and using

rjags (Plummer, 2019) in R (The R Foundation, 2018). Bayesian estimation was used because it allowed us to produce estimates of derived variables within specific probability ranges (i.e., the highest probability density at 50% and 95%), as well as allowing us to calculate the relative contribution of VM vs. AI by direct derivation from model posterior predictions (Appendix A2). After MCMC convergence (checked by visual inspection of trace plots and Gelman-Rubin statistics < 1.1), we sampled each posterior 10,000 times. All models were evaluated in terms of their fit to the mean and coefficient of variance (posterior predictive checks: all Bayesian ps were between 0.1 and 0.9; Hooten & Hobbs, 2015). See Appendix A2 for details on model structure and priors. For model outputs, we report parameter estimates with 95% Bayesian CIs and mean posterior probability of bird abundance/species richness.

3 | RESULTS

We observed 14,656 individual birds from 40 species during the surveys, with approximately 80% (11,925 individuals from 33 species) observed within the village environments and 20% in the surrounding croplands (2731 individuals from 39 species; Table 1). Species that use buildings for nesting were the most abundant group in villages (77% of village birds), while field nesters showed highest abundances in crops (41% of crop birds; Table 1). Noncrop nesters accounted for ~20% of birds in villages and ~40% of individuals in crops. Mean species richness (± SD) in villages and croplands across all sites was 13.4 ± 2.8 and 8.2 ± 2.9 per 6 ha, respectively.

3.1 | Village modernization may suit us, but not the birds

For all farmland species within rural village environments, the level of village modernization (VM) was markedly negatively related to bird abundance, while factors describing the level of agricultural intensification of the surrounding landscape (AI) showed no clear relationships (Table S2). For the subgroups of farmland birds there was some interesting variation from the general pattern seen above. Birds associated with buildings in villages were extremely sensitive to the effects of VM, and virtually unrelated with variables describing AI (Table S2). Noncrop species showed similar relationships with VM and housing density, but responded more to surrounding local landscape features influenced by AI (i.e., cover of residual woodland; Table S2). Patterns of species richness showed no clear links to village and landscape structure (Table S3).

3.2 | Village modernization impacts are not localized to the village environment

Within the crop environment (surveyed from 200–980 m from the village boundaries; Figure 2), there was also a strong negative relationship between the VM and the local abundance of farmland birds (Table S2). An interaction between VM and open residual habitats revealed that declines in overall bird abundance relating to VM predominantly occurred when AI was low (i.e., open residual habitats in croplands were relatively common; Figure 3a and b). However, a second interaction effect between VM and field size indicates modernization effects are greatest when AI is highest (i.e., when field size is large; Figure 3c and d). Reconciling these apparent contradictory effects requires an examination of the different bird subgroups.
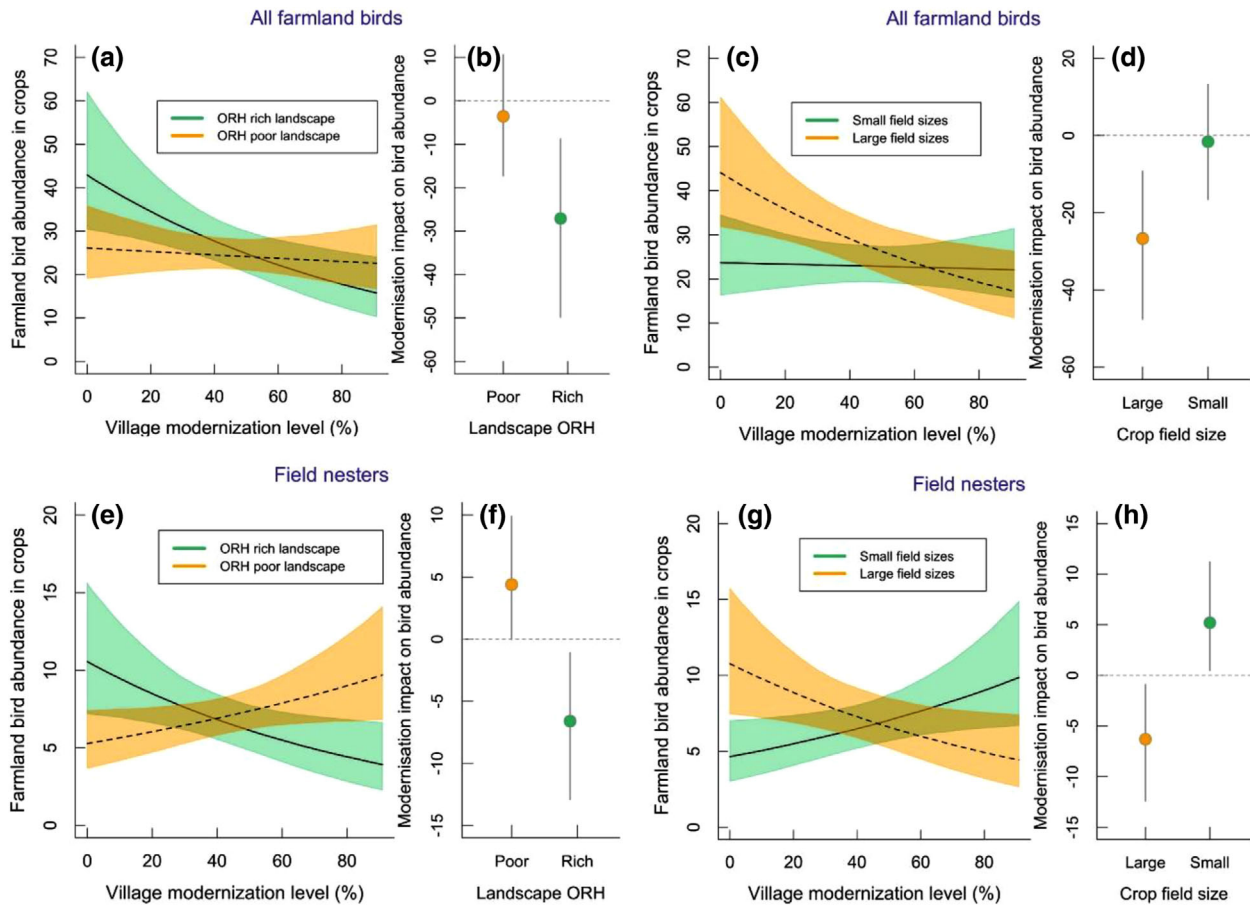
3.3 | Relationships between modernization, intensification, and abundance are not consistent across bird subgroups

In both building and noncrop nesting subgroups, increasing VM was negatively related with abundance regardless of the state of AI (Figure S1). But for field nesting birds, we found opposing effects of modernization interacting with field size and open residual habitats; VM had a positive effect on their abundance when field sizes were small or open residual habitats were few, but modernization had a negative effect on abundance when field sizes were large or open residual habitats were common (Figure 3e–h). Abundance and species richness of farmland species listed in the EU Common bird index (PECBMS, 2018; narrow selection resulting in total of 27 species in our study; see Table S4) showed similar patterns described above (Tables S5 and S6; Figures S2–S4).

3.4 | Village modernization may contribute more than agricultural intensification to farmland bird declines

By making predictions from our Bayesian models by simultaneously varying the ranges of variables describing VM and AI, we could estimate the relative contribution of each major process to farmland bird declines resulting from [low VM + low AI] transitioning to [high VM + high AI] (Figure 4a and b). Here we estimated the contribution of village modernization to the predicted declines of all farmland birds in village environments

FIGURE 3 Relationship between bird abundance in the crop environment and modernization level of the nearest village in landscapes poor and rich in open residual habitats (a–b and e–f) and in landscapes with large and small fields (c–d and g–h). Upper panels show predictions for abundance of all farmland birds and the lower panels represent predictions for abundance of open field nesting species (for species list see Table 1). (a), (c), (e), (g) The posterior mean (black solid and dotted lines) with 95% Bayesian credible intervals. (b), (d), (f), (h) The predicted mean difference and its 95% Bayesian CIs (dot and lines, respectively) in bird abundance between old (i.e., no new or renovated homesteads) and modern villages (i.e., share of new and renovated homesteads = 90%) for the contrasting landscape types. ORH poor and rich landscape = 10 and 90% quantile range of cover of open residual habitats within 2-km radius, respectively; small and large field size = 10 and 90% quantile range of mean field size within 2-km radius, respectively

to be 88%: with agricultural intensification contributing only 12% to expected changes in bird abundance across the observed ranges in these explanatory variables. For birds associated with buildings in villages > 99% of predicted declines was attributed to VM, while for noncrop species VM versus AI was estimated to be 56% versus 44% (Figure 4a).

For all farmland species within the crop environment, VM still explained most (56%) of the predicted declines, despite these birds being observed in the cropland environment (Figure 4b). The overall predicted decline in noncrop species and field nesters was mostly explained by AI (85% and > 99% of the predicted decline, respectively, Figure 4b) while declines in building nesters found in croplands were attributed more to VM (53%; Figure 4b).

4 | DISCUSSION

Our results demonstrate that areas of human habitation are critical habitat areas for many farmland species in agricultural landscapes. Farmland wildlife in Europe and many other parts of the world has adapted through a close association with traditional rural settlements and their surrounding agricultural habitats; thus, it is not surprising that structural and functional changes in rural settlements play an important role in the local abundances of farmland birds. What has been underappreciated in the farmland conservation narrative is that recent changes in the rural way of life, modern design of houses and gardens, and animal husbandry (Antrop, 2004) could all be drivers behind avian farmland biodiversity declines. The natural, direct human dependence on nature in rural areas (e.g., via
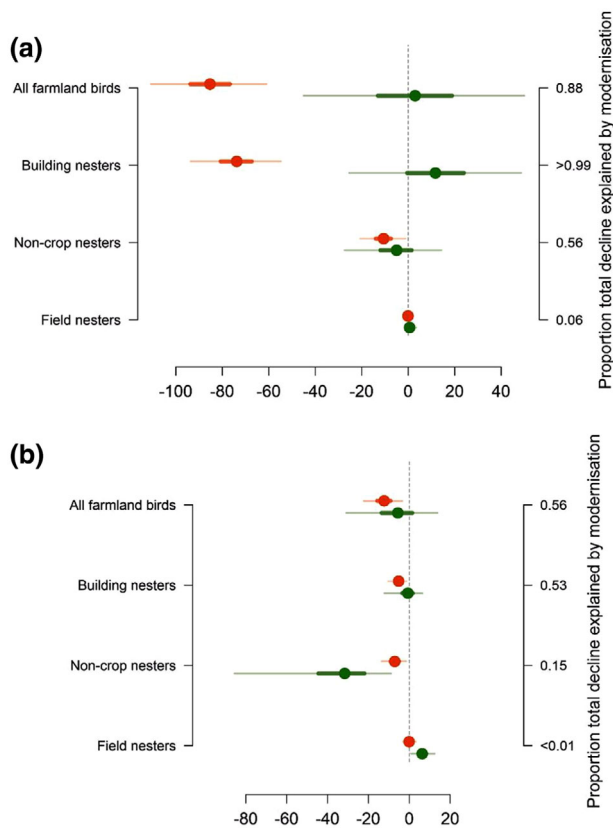
FIGURE 4 Predicted impact of village modernization (red) and agricultural intensification (green) on the absolute number of farmland birds in villages (a) and crops (b) in this study area. Predictions are means (points), 50% (thick line) and 95% (thin line) Bayesian CIs calculated as the posterior distribution of the difference from models fitted to the minimum and maximum range of the modernization gradient. The left axis shows the different ecological subgroups: all farmland birds, building nesters, noncrop nesters, and open field nesting species (for species list see Table 1); the right axis shows the relative contribution of village modernization to any predicted declines, as a proportion of: modernization impact/(modernization + agricultural intensification impact)

small-scale farming) has been lost in many places through urbanization or abandonment of small farm settlements (Angelstam et al., 2003; Antrop, 2004; Mikulcak et al., 2013). Here, we show that an increasing share of new and renovated houses in rural settlements is strongly related to losses in local abundance of farmland bird species that are dependent on village structures for breeding and foraging.

Village modernization was strongly related to bird abundance in crops, reducing the number of building-nesting birds by about 50% irrespective of agricultural intensity. In contrast, the negative impact on noncrop species abundance depended on the level of AI: being highest in crops surrounded by high amount of ORH and within large fields. This suggests that modernization may not only reduce nesting opportunities for building-nesting species

(Rosin et al., 2020), but also reduce food resources for village and crop bird communities. Many farmland species forage in villages (e.g., spilled grain associated with domestic poultry, insects associated with farming animals and residues; Møller, 2001; Šálek et al., 2015). Thus, farmstead removal, modernization or increased cleanliness resulting from industrial-like production might reduce food availability for birds in farmland and be responsible for biodiversity loss in both villages and surrounding crops (Rosin et al., 2016; Šálek et al., 2018; Siriwardena et al., 2008). However, old villages may also be an important source of bird predators (e.g., corvids and domestic cats) with these predators having higher hunting success within field edges (Söderström et al., 1998). This is one explanation why field nesters increased in abundance with village modernization in landscapes with small surrounding fields. Competition with other bird species (e.g., starling *Sturnus vulgaris*, tree sparrow) who utilize open cropland areas in different ways and who largely suffer from high modernization and agricultural intensity could explain why field nesting species increased with village modernization in landscapes with few ORH.

Relatively high farmland bird diversity in villages and positive relationships between bird species richness in cropland and village proximity suggest that villages may act as valuable noncrop habitats supporting and spilling over farmland birds in agricultural landscapes (Hiron et al., 2013, 2015; Rosin et al., 2016; Šálek et al., 2018). The same may be true for other taxa, including pollinators (Baldock et al., 2019; Lowenstein et al., 2015). Village modernization-related variables have never been considered to explain farmland bird population trends shown by Farmland Bird Index (PECBMS, 2018) or in previous studies (Reif & Vermouzek, 2019; Siriwardena et al., 2000; Wretenberg et al., 2007). We provide novel evidence that highlights a crucial and understudied change in rural landscapes that, together with agricultural intensification, likely explains why farmland birds have declined so dramatically after the second World War in Europe and continue to do so in some areas. We cannot rule out the possibility that some building modernization in this study is associated with AI (e.g., higher incomes from higher production intensity favoring modernization of the built environment), and that relative importance of these VM-AI relationships likely differ across Europe and other parts of the world. Nevertheless, identifying drivers behind general declines calls for acknowledgement that "farmland species" require multiple habitats (Benton et al., 2003) and that villages and farmsteads are one of these key habitats (Ahnström et al., 2008; Hiron et al., 2013; Rosin et al., 2016; Šálek et al., 2018).

Currently, farmland bird biodiversity conservation is focused almost exclusively on the cropland environment

(Gawith & Hodge, 2019), with limited success considering resources invested (Gamero et al., 2017). Problems associated with village modernization are currently exacerbated by reduction of cavities in the external surfaces of buildings through energy-efficient retrofitting and loss of access to farm building interior driven by the EU regulations (Rosin et al., 2020). The latest EU's strategy "A Renovation Wave for Europe" aims for 35 million building units to be energy-efficient by 2030 as a major measure to reduce greenhouse gas emissions on the continent (European Commission, 2020); our results suggest this puts many farmland birds at risk of further population declines.

4.1 | Policy recommendations

Sustainable rural development, with an eye to biodiversity conservation, must include conservation of village ecological values: that is, maintenance of high availability of nesting sites (through protecting and developing bird-friendly architecture; Rosin et al., 2020) and food resources (supporting small family-based farmsteads and supplementary feeding; Rosin et al., 2016; Siriwardena et al., 2008). Measures aimed at improving or conserving important habitats linked to villages and rural settlements might be needed globally and should be urgently developed and included in the European Green Deal (European Commission, 2020) and CAP (Common Agriculture Policy; Mikulcak et al., 2013; Pe'er et al., 2014; Wretenberg et al., 2007), especially the current funding structure of European agrienvironmental schemes (Batáry, Dicks, Kleijn, & Sutherland, 2015; Kleijn & Sutherland, 2003). It is also essential to investigate the magnitude of ecosystem services that village structures support on adjacent fields (e.g., pest control, pollination). Educational programs making people aware of the importance of their farmsteads or homesteads for farmland biodiversity would be of great value. Such conservation measures are likely to go hand-in-hand with needed protection of traditional cultural landscapes and encourage a reconnection of people to nature in rural areas (Angelstam et al., 2003; Antrop, 2000; Fischer et al., 2012). Thus, this broader consideration of conservation policy in agricultural landscapes would have likely positive impacts on people's well-being in addition to farmland biodiversity.

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