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Varying potential of conservation tools of the Common Agricultural Policy for farmland bird preservation

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Abstract

Agri-environment schemes (AES) and greening of the Common Agricultural Policy (CAP) are crucial tools for biodiversity conservation in Europe. However, they have not been associated formally to any performance monitoring program that supports their actual benefits for biodiversity, and their effectiveness is recurrently questioned.

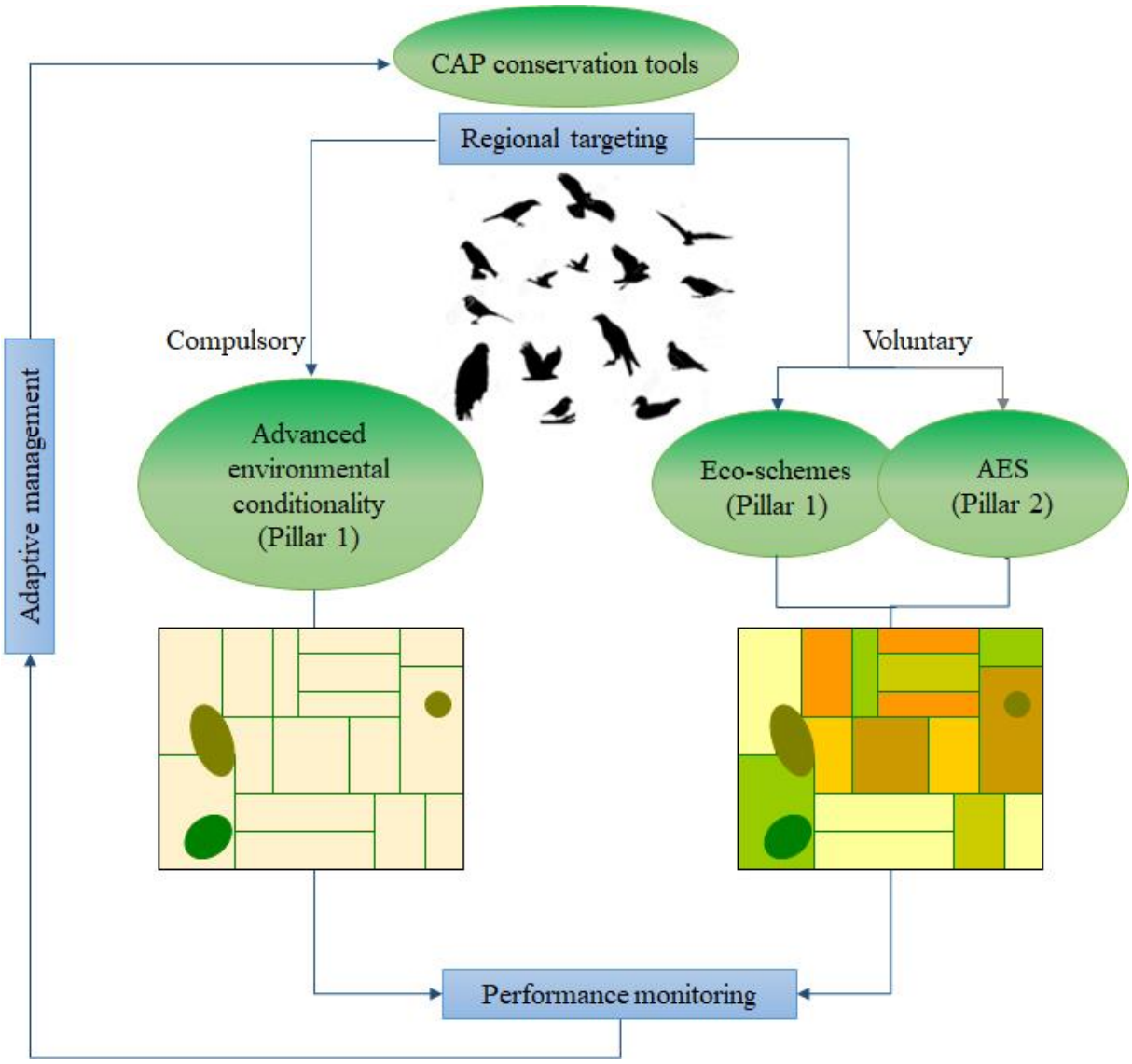
We present an extensive evaluation of the potential of CAP conservation tools to support farmland bird diversity throughout the most representative cereal regions in Spain. We explore bird diversity responses to AES application in pairs of cereal plots with and without AES. We also explore bird responses to a set of habitat indicators, both of productive (farmed) and semi-natural components (i.e., field margins and natural vegetation remnants), within plots and in the surrounding landscape. We use these habitat indicators as proxies of distinct greening measures (e.g., hedges, fallow, crop diversification).

Our results point at the prospective success of measures focused on promoting, particularly at landscape scales, certain productive habitats (e.g., fallow land and legume crops), mainly but not exclusively for open land birds. Promoting semi-natural habitats (both areal and linear elements) also resulted positive, primarily for forest and ecotone birds, but also open land birds.

Our results evince high variability in the capacity of AES and distinct greening measures to support bird diversity among regions and groups of birds. More regionally-targeted conservation measures (i.e., focused on specific requirements of targets, considering explicitly regional species pools and landscape constraints) are thus required. These measures could be assembled in the new CAP by means of compulsory measures applied throughout the agricultural landscape (i.e., advanced environmental conditionality likely replacing cross-compliance and greening) and voluntary instruments (i.e., eco-schemes and AES) with

enough farmers' uptake that ensures its impact at landscape scale. Performance evaluation and subsequent adaptation based on the results obtained ought to accompany the implementation of conservation tools.

Graphical abstract



Highlights:

- Local habitat management only affect abundance of foraging and wintering birds
- Landscape configuration and composition alone affect diversity of breeding birds
- Bird diversity responses greatly vary across regions, seasons and groups of birds
- Regionally-targeted conservation tools should be implemented at landscape scale
- Performance monitoring and subsequent adaptation of these tools should be mandatory

Keywords:

Agri-environment schemes; Eco-schemes; Environmental conditionality; Environmental Focus Areas; Green and blue infrastructure; Greening.

1. Introduction

Biodiversity conservation greatly depends on its maintenance in anthropized landscapes worldwide, and especially in regions with a long history of human activities like Europe (Foley et al., 2011; Mendenhall et al., 2014). Agricultural areas in particular host the most important habitats for more than half of bird species of conservation concern in Europe (Donald et al., 2006; Traba and Morales, 2019). Despite the huge conservation efforts and investments made since the establishment of agri-environment schemes (AES) in the European Common Agricultural Policy (CAP) in 1992, agricultural intensification and abandonment of extensive agriculture continue being major threats to biodiversity in Europe (Navarro and López-Bao, 2018). AES are part of the Rural Development policy (CAP pillar 2) and account for around 7 % of the total CAP budget (ca. € 30 billion in the period 2014–2020; Navarro and López-Bao, 2018; Pe'er et al., 2014). AES consist on voluntary contracts with farmers that receive a payment for implementing in their farms a set of management practices that are expected to benefit biodiversity, the environment and/or, since the last CAP reform in 2014, the climate (e.g., reduce fertilizer or pesticide applications, create field margins or uncropped areas).

Although AES have generally been found to promote biodiversity (e.g., in terms of species richness and abundance; Kleijn et al., 2006), they have been pointed to suffer from too general aims and poor regional contextualization to account for specific conservation targets (Díaz and Concepción, 2016; Kleijn et al., 2011). AES local and voluntary application has also been argued to limit AES effectiveness, which would strongly depend on the overall regional uptake to have a significant impact on biodiversity (Batáry et al., 2015; Daskalova et al., 2019). AES effectiveness has been shown to be constrained by surrounding landscape, which would limit the number of species that fields or farms could harbour (Concepción et al., 2012, 2008). Semi-natural habitats and landscape elements, such as pastures, woodlands,

hedgerows, field margins, streams or ponds, are more and more lacking in agricultural landscapes. These elements, now called *Green and Blue Infrastructure* (GBI), are considered essential for the conservation of biodiversity, and their promotion all over the agricultural landscape has been pointed as pre-requisite for AES to successfully support biodiversity in fields or farms where applied (Concepción et al., 2012).

All this knowledge about AES limitations has however not been properly incorporated in the different CAP reforms so far. In fact, AES effectiveness has not improved since 2007 as compared to the previous programming period (2000-2006) according to available scientific assessments (Batáry et al., 2015). The last CAP reform in 2014 has somehow tried to counteract these limitations through the promotion of GBI all over European agricultural landscapes, by means of "greening". It consists on a set of obligatory measures for farmers to receive their area-based direct payments (CAP pillar 1), including the maintenance of permanent grasslands, and the promotion of crop diversification and environmental focus areas (EFAs) within farms (5% of arable land). EFAs encompass both productive and non-productive habitats, such as land lying fallow, agroforestry, green covers, nitrogen-fixing crops, and landscape features, like hedges, field margins, ponds or traditional stone walls (Appendix A). All greening options are not eligible in some member states, but they are instead included in cross-compliance (compulsory basic requirements related to environment, public health and animal welfare according to CAP pillar 1), for instance hedges in Spain, where only a few EFAs (i.e., fallow land, nitrogen fixing crops, green covers and agroforestry) are eligible within greening.

Greening has been launched as key conservation tool due to its extensive application throughout the agricultural landscape. However, its conservation potential has been questioned, given the lack of management prescriptions associated to most greening options, and the high number of exemptions allowed (Dicks et al., 2014; Pe'er et al., 2014). For

instance, small farmers and those devoted to organic agriculture and permanent crops (vineyards, olive groves and orchards) have automatic right to direct payments without any additional requirement (see Marsden and Jay 2017, 2018 for a detailed review on greening prescriptions and recent changes). Greening has also been pointed to promote the declaration of EFAs already present within farms, rather than the creation of new GBI, supporting options that farmers would carry out in any case (European Commission, 2017; Underwood and Tucker, 2016). EFA options applied most are those related with productive agriculture (e.g., nitrogen-fixing and catch crops, fallow land), which are easily integrated in the existing farming system. Alternative options, such as landscape features, are expected to be more valuable for biodiversity but they are less attractive for farmers due to greater opportunity costs, stricter requirements and controls, and subsequent sanction risk (Marsden et al., 2017; Marsden and Jay, 2018a; Pe'er et al., 2017).

Recent changes made in greening in 2018 are expected to have mixed impacts. On the one hand, additional incentives to some productive EFAs, like nitrogen-fixing or catch crops, and exceptions for larger farms to accomplish with crop diversification are hardly expected to enhance biodiversity; while the ban of plant protection products in productive EFAs is supposed to greatly benefit biodiversity (Marsden et al., 2018). However, as occurs with AES, greening implementation has not either been associated to any systematic monitoring or evaluation of its actual impacts on biodiversity (Pe'er et al., 2017, 2014). Performance evaluation of CAP conservation tools is absolutely necessary for their redesign and streamlining (Díaz and Concepción, 2016). This is especially timely now that the next CAP programming period (2021-2028) is under discussion (Marsden and Jay, 2018b). In particular, the current frame of compulsory measures, i.e., cross-compliance + greening (pillar 1), will probably be replaced with an advanced environmental conditionality (compulsory) + eco-schemes (voluntary), combined with AES (pillar 2) which will continue operating. Member

states will have more flexibility and autonomy for transferring funds between pillars, and designing and applying eco-schemes and AES. This potentially enables a better regional contextualization and targeting of conservation tools. The Commission in turn will pay further attention to the coordination and achievement of conservation targets through the "performance monitoring and evaluation framework" (Marsden and Jay, 2018b).

Here we evaluate the potential of CAP conservation tools, including AES (pillar 2), greening and cross-compliance (pillar 1), to support avian diversity in Spain. We focus on extensive dry cereal croplands, which extend throughout most of the Spanish territory and host the largest share of the populations of most farmland birds of European conservation concern. Consequently, AES aimed at open land birds' conservation customary applied therein are the most widely applied in Spain (Concepción and Díaz, 2011; Kleijn et al., 2006). We use data on bird diversity (species richness and abundance) in pairs of cereal plots managed under AES and conventionally (control), and allocated throughout the most representative cereal regions in Spain (i.e., Castilla y León, Castilla-La Mancha and Ebro basin) in spring 2012 and winter 2010/11. Besides direct measurements of AES application in plots, we select a set of indicators, both of the composition and configuration of semi-natural and productive habitats within plots and in the surrounding landscape. We use these indicators as proxies of greening and cross-compliance measures (i.e., maintenance of permanent crops, grasslands, EFAs, landscape features, reduced farm sizes, and crop diversification), since they may be linked to the implementation of these measures in farmland. We analyse the relationships between (1) AES and habitat and landscape indicators linked to CAP conservation tools and (2) the abundance and species richness of farmland birds during the reproductive season in spring, but also in winter, to infer the potential impact of different CAP conservation tools to support bird diversity and make clear policy enhancement recommendations.

Overall, we expect varying effects of AES and the distinct habitat predictors linked to CAP conservation tools on bird diversity among regions, seasons and groups of organisms investigated. In particular, we expect positive effects of AES on bird diversity (Concepción et al., 2008; Kleijn et al., 2006), especially for open land birds (i.e., the target of AES applied in the evaluated systems; Concepción and Díaz, 2010, 2011) and in spring, when most management prescriptions are applied (though their positive effects may last until winter if prescriptions affect land-use management beyond the reproductive season; see Díaz et al., 2012). We also assume that the distinct habitat predictors linked to greening will strongly affect bird diversity, especially at landscape scale, given the high size, mobility and home ranges of birds (Concepción and Díaz, 2011, 2010; Gabriel et al., 2010; Moreira et al., 2005). We particularly expect overall negative effects of field size, as well as positive effects of crop diversification (Fahrig et al., 2015, 2011) and EFAs, mostly of semi-natural habitats (both, linear and areal elements (Pe'er et al., 2014; Underwood and Tucker, 2016). Nonetheless, we also forecast substantially varying effects of such habitat predictors depending on the specific requirements of the group of birds analysed and the regional and landscape contexts (Díaz and Concepción, 2016). For instance, open land birds will likely take advantage of open landscapes with large fields and amount of cultivated and fallow land (Concepción and Díaz, 2011; Giralt et al., 2018; Morales et al., 2015; Moreira et al., 2005; Pickett and Siriwardena, 2011; Robleño et al., 2017). Forest and ecotone species that rely on woody vegetation will in contrast benefit from semi-natural habitats and linear elements, which in turn may be detrimental for open land birds (Concepción and Díaz, 2010; Moreira et al., 2005; Reino et al., 2009). Bird species prevailing in regional pools will consequently determine the overall effects of distinct predictors on bird diversity. As a result of this extensive evaluation, we estimate what specific conservation measures should have the best prospective ecological success in the analysed systems, and how this can be integrated in the new CAP.

2. Methods

2.1. Study sites

We selected a total of 14 study areas covering the main agricultural regions specialized in cereal cultivation in Spain (i.e., Castilla y León, Castilla-La Mancha and Ebro basin; Table 1; Figure 1). These regions vary in landscape configuration and composition, from opener and crop-dominated areas in Castilla y León to finer landscapes with greater mixture of productive and semi-natural habitats in Castilla-La Mancha, and especially in the Ebro region. These regions in addition support important communities of steppe birds and AES aimed at the conservation of these birds have routinely been applied therein since mid-1990s. AES consisted on (1) reduced application of fertilizers and plant protection products, (2) modification of farming cycle (e.g., maintenance of stubbles, fallow land and legume crops), both aiming at enhancing food availability for birds, and (3) adjusting farming calendar (ploughing, mowing or harvesting) to the life cycle of birds, aiming at enhancing adult and nestling survival (Concepción and Díaz, 2011, 2010; Díaz et al., 2012; Llusia and Oñate, 2005; See Appendix B for a list of AES prescriptions per study area).

We selected three to eight pairs of nearby cereal fields with and without AES in each study area (Table 1). Field pairs were formed by one field managed under AES, and the other farmed in the conventional way for each region, which was used as control. Fields within pairs were as similar as possible in factors other than management potentially affecting bird diversity (e.g., field shape and size, soil, slope, and landscape context). Based on selected fields, plots of 12.5 ha (including fields and their surroundings, always cropland, in half of the cases where fields were smaller) were established as survey units in order to standardize sampled areas (see Concepción et al., 2008; Kleijn et al., 2006 for similar designs).

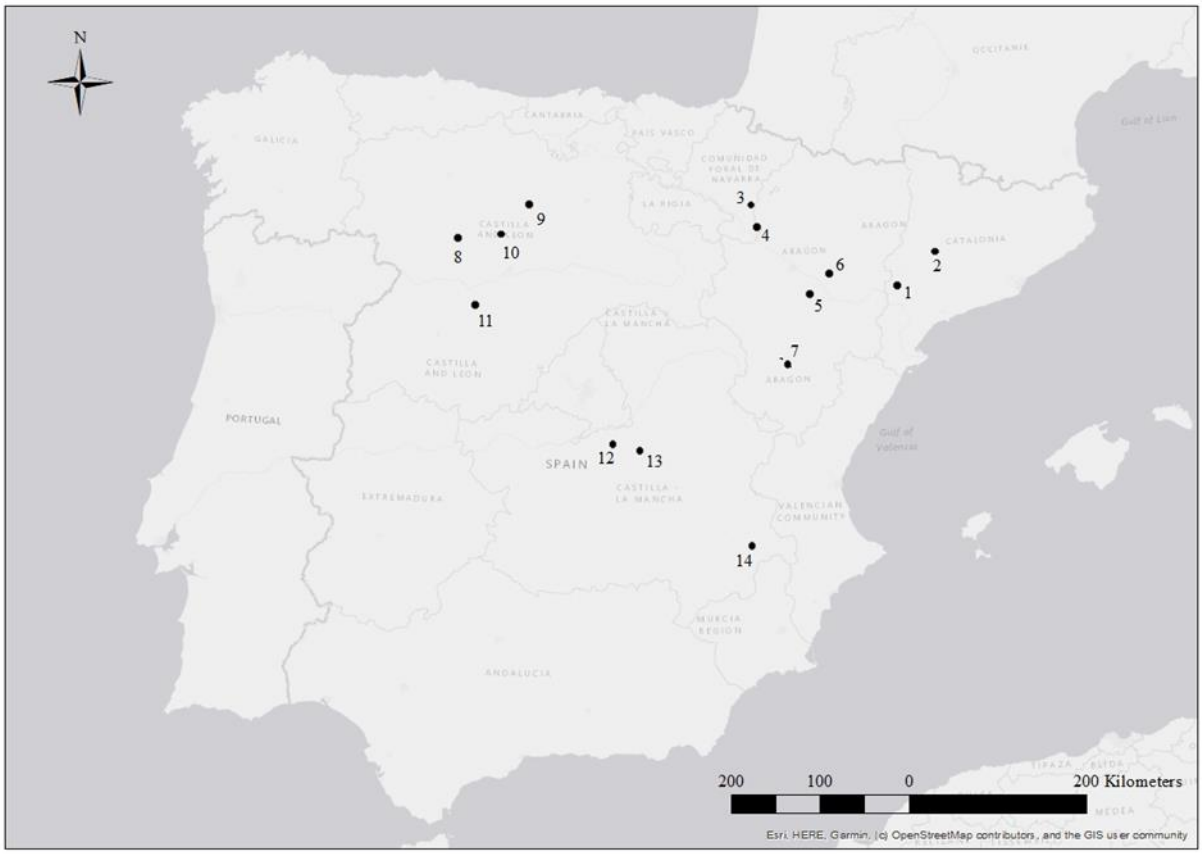


Figure 1. Location of the 14 study areas distributed throughout the main cereal regions in Spain: Ebro basin, including Catalonia (1, 2), Navarra (3, 4) and Aragón (5 - 7), Castilla y León (8 - 11), and Castilla-La Mancha (12 - 14). Numbers refer to the study areas listed in Table 1.

Table 1. Number of plots (12.5 ha each) per study area and season. See also Figure 1.

Agricultural region	**Winter 2010/11**	**Spring 2012**
Ebro basin (north-east Spain):		
1. Segrià (Lleida)	8	16
2. Bellmunt (Lleida)	10	-
3. El Plano (Navarra)	16	16
4. Rincón del Bú (Navarra)	10	-
5. Belchite (Zaragoza)	6	10
6. Monegrillos (Zaragoza)	12	-
7. Campo Visiedo (Teruel)	8	14
Castilla y León (north-central Spain):		
8. Penillanuras (Zamora)	10	16
9. Camino de Santiago (Palencia)	12	12
10. La Nava (Palencia)	8	-
11. Tierra de Campiñas (Valladolid)	14	14
Castilla-La Mancha (south-central Spain):		
12. La Mancha Norte (Toledo)	6	6
13. La Mancha Norte (Cuenca)	12	16
14. Este de Albacete (Albacete)	8	16

2.2. Data collection

Bird surveys were carried out in 136 plots allocated in 10 study areas covering the three main cereal regions in Spain (i.e., Castilla-La Mancha, Castilla y León and Ebro basin) four times during the breeding season of 2012 (at 7–10 days' intervals between late April and early June). Paired plots were always visited in the same dates by the same observer, who walked slowly all through and around each plot during around 20 min, early in the morning (from sunrise to 11:00 am) in days with good meteorological conditions. All bird contacts along the four visits were mapped on aerial photographs and bird territories were afterwards drawn following Bibby et al. (1992). We then calculated the number of species and territories of birds breeding in each plot (species richness and abundance of breeding birds), and the total number of species and individuals found both breeding and foraging in plots (species richness and abundance of foraging birds) during the reproductive season. Birds were also surveyed during winter 2010/11 in 140 paired plots (half of them managed under AES the former spring and the other half under conventional management) allocated in 14 study areas (Table 1). Winter surveys consisted on walks throughout plots, in the morning (from sunrise to 13:00 am) in days with good meteorological conditions, repeated three times between late December and early February at intervals of 3-4 weeks. We summed the total number of species (richness) and individuals (abundance) of wintering birds in each plot. Species richness and abundance metrics were calculated for the overall pool of bird species found in study plots, and for the groups of open land and forest and ecotone species separately. Bird species closely associated to cultivated habitats both, for foraging and nesting were classified as open land birds according to the characterization of steppe birds by Suárez et al. (1997). The rest of species that may forage on crops, but customarily breed in other substrates (woody vegetation, wetlands, rocks, etc.) were aggregated as forest and ecotone birds (Appendix C; see also Concepción and Díaz, 2010, 2011 for a similar approach).

To estimate landscape and local habitat configuration and composition, we delimited distinct types of habitats and boundaries with semi-natural vegetation, at either plot (12.5 ha) or surrounding landscape (500 m radius buffer area) scales, on aerial photographs during field surveys, and afterwards incorporated this information in a GIS (ArcGIS; ESRI, 2018).We then calculated metrics that summarize independently landscape and local habitat configuration and composition (including both, the productive and semi-natural components of agricultural landscapes). Metrics were also selected to act as proxies that cover the different options included in CAP greening or cross-compliance (i.e., maintenance of permanent grasslands, EFAs and landscape features, reduced farm sizes, crop diversification, and permanent crops). Mean field size (ha) and length of boundaries with semi-natural (both, herbaceous and woody) vegetation (m) in plots and surrounding buffers were selected as local habitat and landscape configuration metrics, respectively. Percentage area of semi-natural habitats (including grass-, shrub- and woodlands), permanent crops (vineyards and olive groves), cereals, nitrogen-fixing crops (grain and forage legumes), fallow land and stubbles, and richness of herbaceous crops were measured in plots (in spring and winter) and surrounding buffers (only in spring) as local habitat and landscape compositional metrics, respectively (see Appendix D for details).

2.3. Data analysis

We used generalized linear mixed models (GLMMs; Pinheiro and Bates, 2000), with Poisson distributions of errors and log-link functions. Response variables were species richness and abundance in plots, both of foraging and breeding birds in spring, and of wintering birds and, for (a) all bird species together and for (b) open land and (c) forest and ecotone species independently. We made separate analyses for winter and spring to account for likely seasonal

effects on bird diversity and differences in available explanatory variables for each dataset (landscape variables were not available in winter dataset). We established four separate sets of explanatory parameters aiming at unravelling (a) local habitat (12.5 ha plots) *vs.* landscape (surrounding 500 m radius buffers), and (b) configurational *vs.* compositional effects on bird diversity (see description above and Appendix D for details). Pearson's product-moment correlations between individual explanatory parameters were all below 0.7, which indicates no collinearity concerns between these variables (Dormann et al., 2013). Plot pairs nested within study areas (study area/pair), were included as random factors to account for the paired and nested sampling design. We included local management (AES *vs.* conventional) of plots within pairs as factor in models to investigate the expected positive effects of AES on bird diversity.

For each response variable, we performed a full set of GLMMs with all possible combinations of predictors, ranked them according to the second-order Akaike's information criterion (AICc, corrected for finite sample sizes), and selected the most plausible (best fitted) model according to this criterion (that with the lowest AICc; Burnham and Anderson, 2002). We used this procedure to reduce the number of non-explanatory parameters within models while avoiding increased probability of type I errors associated to model selection procedures based on step-wise term deletion and model-comparison significance tests (Mundry and Nunn, 2009; Whittingham et al., 2006). As we expected that regional species pools would significantly influence bird responses, we considered the agricultural region (i.e., Castilla y León, Castilla-La Mancha and Ebro basin) where the 14 study areas were allocated as factor in models (see Table 1 and Figure 1). After proving the generalized significance of interactions between the factor agricultural region and the whole set of explanatory parameters, we performed separate models for each agricultural region in addition to the overall model including the whole dataset for the three agricultural regions (see Appendix F).

Statistical analyses were performed with R version 3.5.1 (R Core Team, 2018) using the packages 'lme4' (Bates et al., 2015) and 'MuMIn' (Bartón, 2019).

3. Results

Overall, we found 106 species of birds, 71 in winter and 85 in spring. Out of them, 23 were open land species. Open land birds prevailed in Castilla y León (76 and 86% of total abundance in winter and spring, respectively), and secondary Castilla-La Mancha (40 and 81% in winter and spring, respectively), while forest and ecotone species were more abundant in the Ebro region (64 and 24% in winter and spring, respectively; see Appendix C).

Results of GLMMs (Figures 2 – 5; Appendix E) show that local management (AES) and habitat configuration within plots mostly affected the abundance of foraging and wintering birds (Figure 2a,c). In contrast, landscape configuration and composition showed stronger effects, affecting both bird abundance and species richness of either foraging and breeding birds (Figure 2a,b). Sign and magnitude of these effects varied among regions and groups of birds considered, as detailed in the following sections.

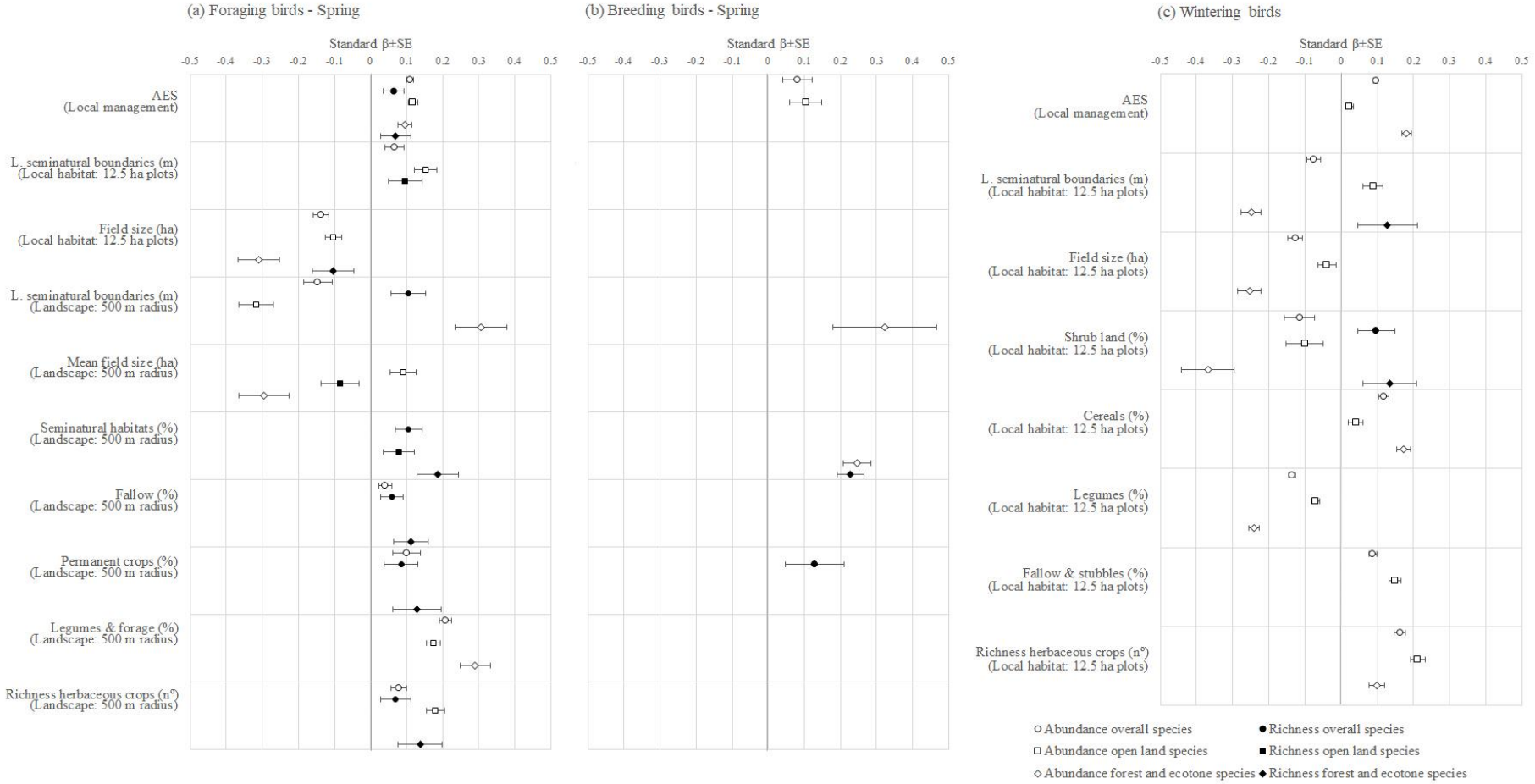


Figure 2. Normalized coefficients (β ± SE) of effects included in best fitted models (lowest AICc) testing the effects of local management (AES vs. conventional), local habitat (12.5 ha plots) and surrounding landscape (500 m radius buffers) configuration and composition on species richness and abundance of (a) foraging and (b) breeding birds in spring, as well as (c) wintering birds, both for all bird species together, and for open land and forest and ecotone species independently in the whole study area.

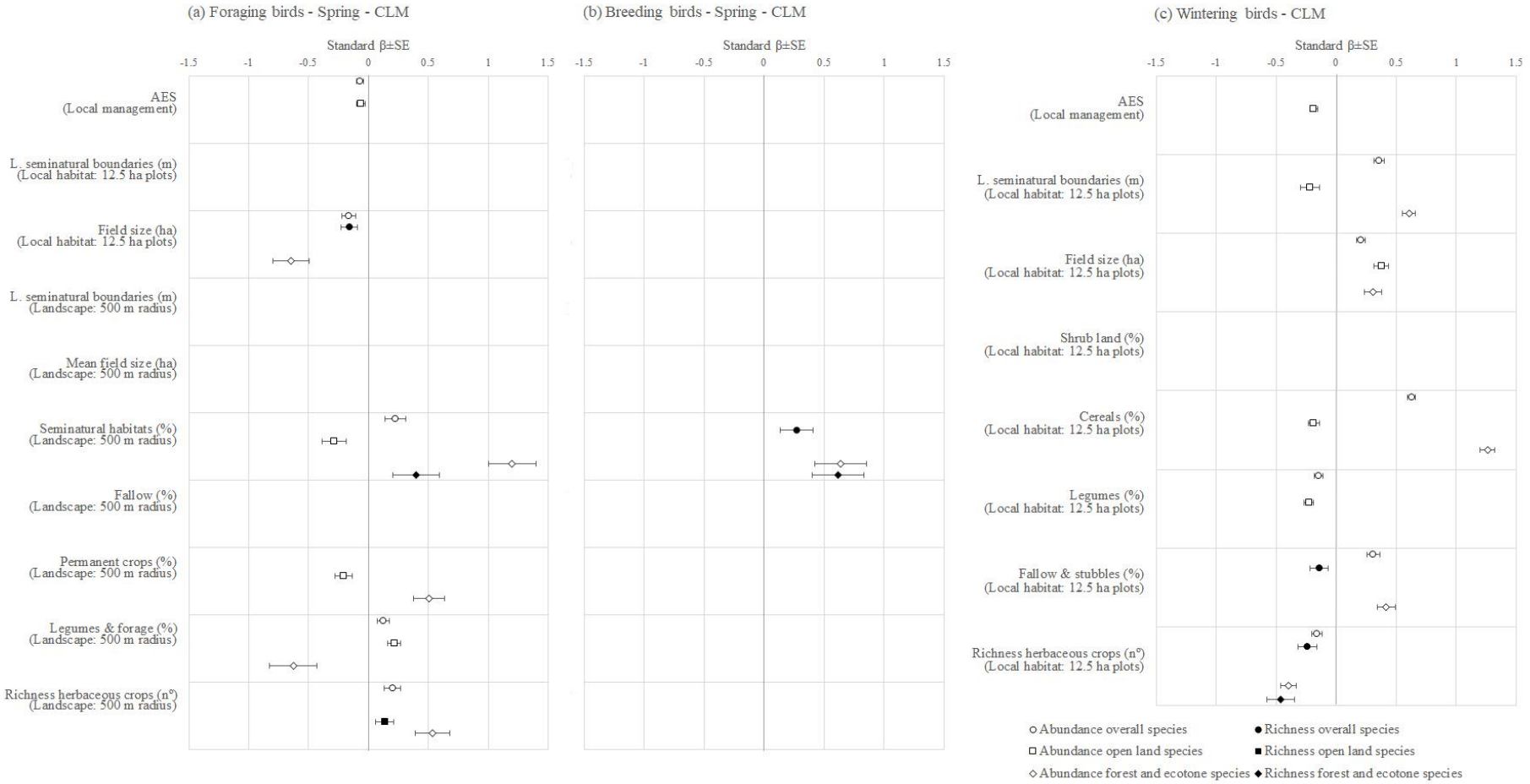


Figure 3. Normalized coefficients (β ± SE) of effects included in best fitted models (lowest AICc) testing the effects of local management (AES vs. conventional), local habitat (12.5 ha plots) and surrounding landscape (500 m radius buffers) configuration and composition on species richness and abundance of (a) foraging and (b) breeding birds in spring, as well as (c) wintering birds, both for all bird species together, and for open land and forest and ecotone species independently in Castilla-La Mancha**.**

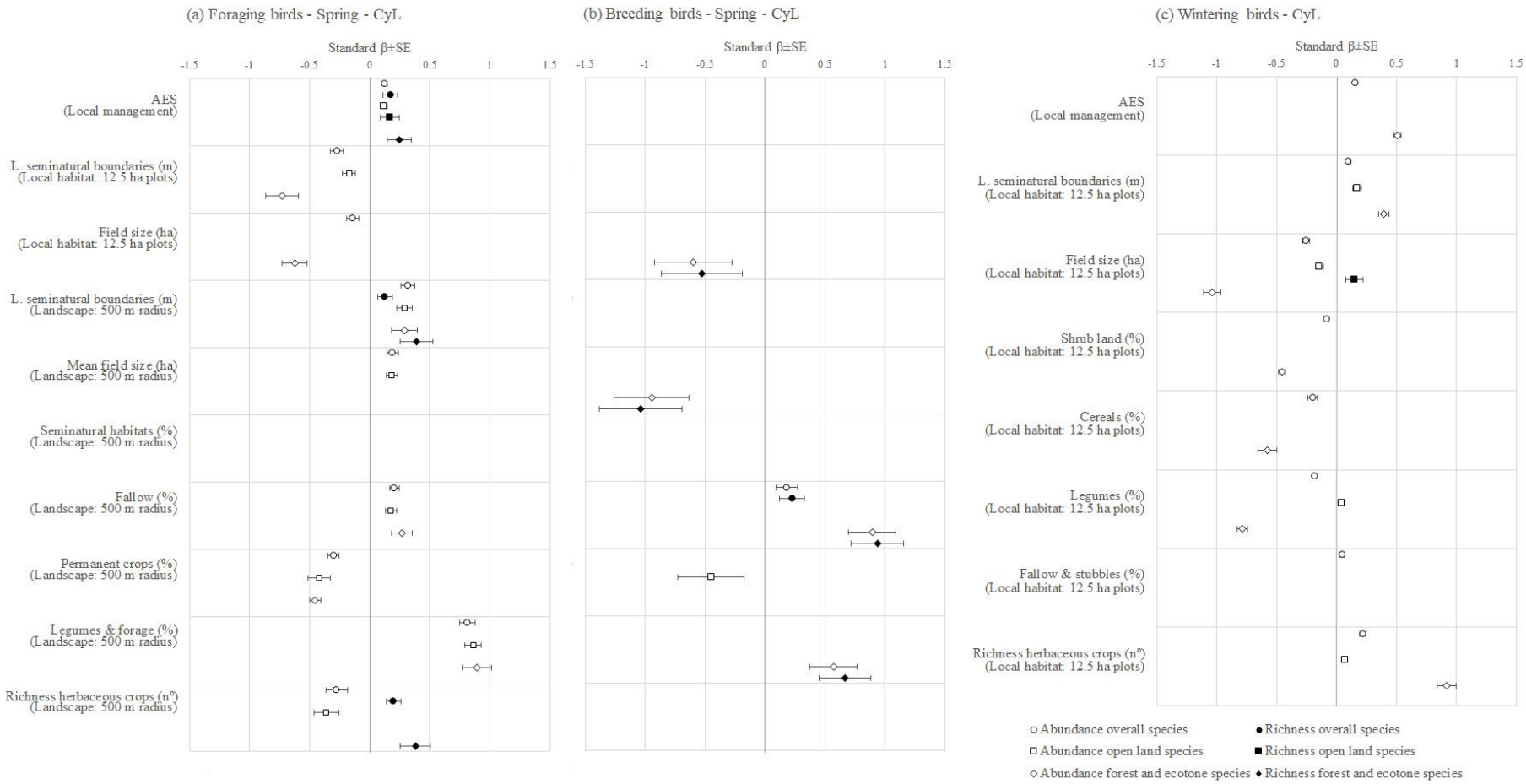


Figure 4. Normalized coefficients (β ± SE) of effects included in best fitted models (lowest AICc) testing the effects of local management (AES vs. conventional), local habitat (12.5 ha plots) and surrounding landscape (500 m radius buffers) configuration and composition on species richness and abundance of (a) foraging and (b) breeding birds in spring, as well as (c) wintering birds, both for all bird species together, and for open land and forest and ecotone species independently in Castilla y León.

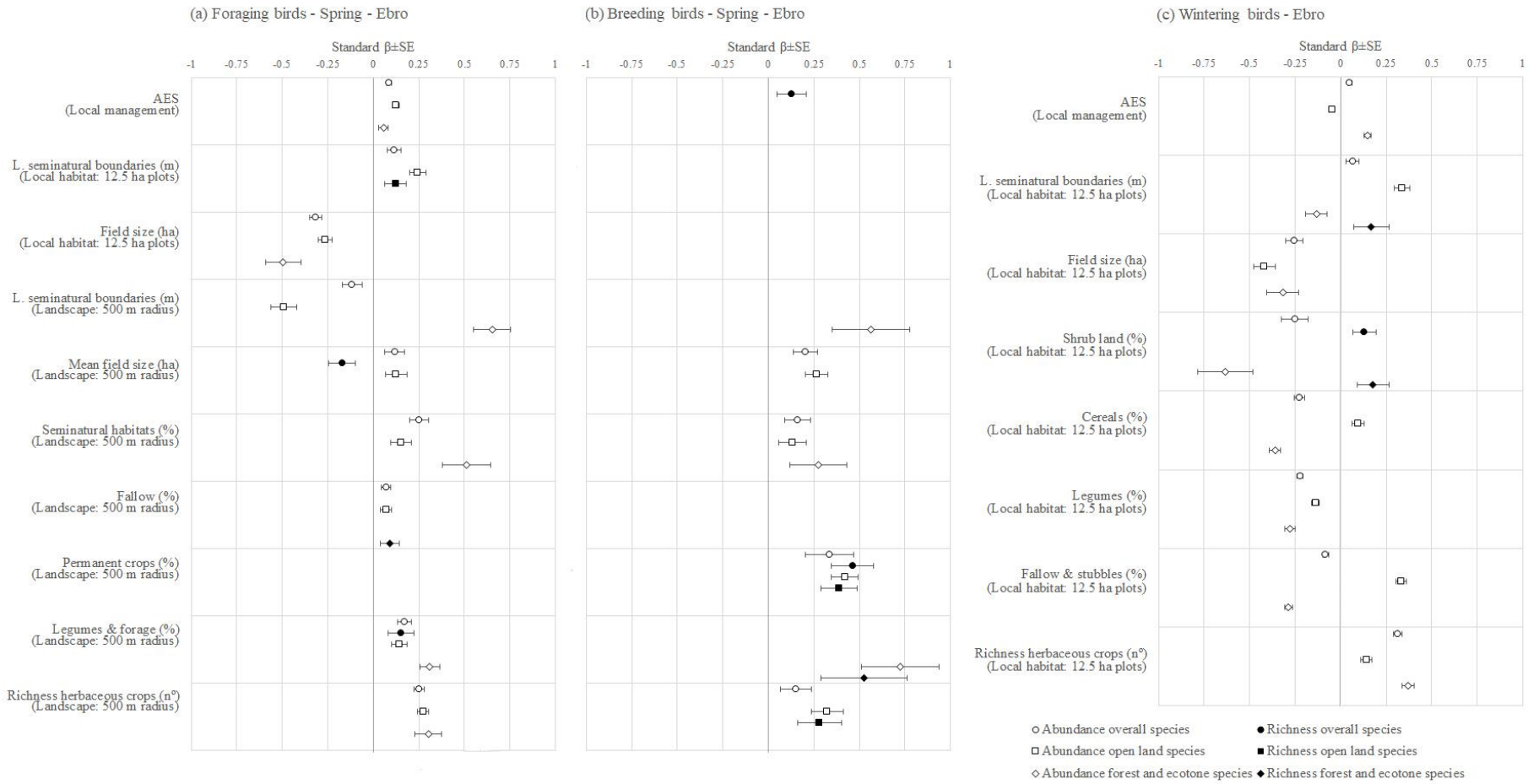


Figure 5. Normalized coefficients (β ± SE) of effects included in best fitted models (lowest AICc) testing the effects of local management (AES vs. conventional), local habitat (12.5 ha plots) and surrounding landscape (500 m radius buffers) configuration and composition on species richness and abundance of (a) foraging and (b) breeding birds in spring, as well as (c) wintering birds, both for all bird species together, and for open land and forest and ecotone species independently in Ebro basin.

3.1. Local management (AES)

Abundance and richness of overall foraging birds increased with the application of AES (Figure 2a). This also occurred with the abundance, both of open land and forest and ecotone birds, and marginally with the richness of forest and ecotone bird species (Figure 2a, increases range in plots with AES: 6 to 12 %; see detailed results in Appendix E). For breeding birds, positive responses to AES application were only found for bird abundance both, of overall and open land bird species (up to 10 % increases, Figure 2b). Interestingly, bird abundance during winter also increased in plots where AES had been applied the spring before, either for overall, open land or forest and ecotone bird species (2 – 18 % increases, Figure 2c). AES effectiveness differed among regions: AES resulted especially effective in Castilla y León region, where, besides abundance, they also increased bird richness both, of overall and open land foraging bird species (12 to 25 % increases, Figure 3a). In Castilla-La Mancha, however, we found negative relationships between AES and the abundance of overall and open land foraging bird species in spring and winter (7 and 18 % decreases in spring and winter, respectively, Figure 4a,c).

3.2. Local habitat and landscape configuration

3.2.1. Patches

Consistent negative relationships between average field size within plots and bird diversity were found in the whole study area and in the three agricultural regions individually, in particular for the abundance of spring foraging and wintering birds, and affecting most overall and forest and ecotone birds (Figures 2-5). However, in Castilla-La Mancha in winter the abundance of all groups of birds (either overall, open land or forest and ecotone species) increased with field size (Figure 4c). In Castilla y León, negative relationships with field size

were the rule for either foraging, breeding and wintering birds, but species richness of wintering open land birds in winter slightly increased with average field size in plots (Figure 3).

Mean field size at the landscape scale also showed negative relationships with the abundance of forest and ecotone foraging birds, but positive relationships with the abundance of open land foraging birds (Figure 2a). Individual results for the different agricultural regions show that the abundance of overall and open land foraging birds increased with mean field size in Castilla y León (Figure 3a) and Ebro regions (Figure 5a). In the latter, abundance of overall and open land breeding birds also increased with mean field size, while overall foraging bird species richness decreased (Figure 5a,b). In Castilla y León abundance and species richness of forest and ecotone breeding birds also decreased as mean field size increased (Figure 3b).

3.2.2. Linear elements

Length of semi-natural boundaries, both within plots and in the surrounding landscape, presented overall positive relationships with bird diversity (Figure 2). Many differences depending on the spatial scale (plot *vs.* landscape), agricultural regions, season (spring *vs.* winter) and groups of birds (open land *vs.* forest and ecotone) considered however arose. In Castilla y León, abundance of overall, open land, and forest and ecotone foraging birds decreased in spring (Figure 3a), but increased in winter as the length of semi-natural boundaries within plots grew (Figure 3c). Abundance of all these groups of spring foraging birds, as well as their species richness in the case of overall and forest and ecotone birds, in contrast, increased with length of semi-natural boundaries in the landscape (Figure 3a). In the Ebro region in spring overall foraging bird abundance, as well as abundance and species

richness of foraging open land birds increased with length of semi-natural boundaries within plots (Figure 5a). The abundance of forest and ecotone, both foraging and breeding, birds increased as the length of semi-natural boundaries in the landscape grew. In contrast, the abundance of overall and open land foraging birds decreased with the length of these boundaries in the landscape (Figure 5a,b). In winter, forest and ecotone bird abundance decreased, while their species richness marginally increased as the length of semi-natural boundaries within plots grew. Abundance of open land and marginally overall birds also increased with the length of semi-natural boundaries within plots (Figure 5c). In Castilla-La Mancha, semi-natural boundaries only had effects on bird diversity in winter, when the abundance of overall and forest and ecotone birds increased, while open land birds' abundance decreased, with increasing length of semi-natural boundaries within plots (Figure 4c).

3.3. Local habitat and landscape composition

3.3.1. Semi-natural components

In spring, species richness of overall, forest and ecotone, and marginally open land foraging birds, as well as the abundance and richness of forest and ecotone breeding bird species, augmented as the proportion of semi-natural habitats (including woodland, shrubs or uncultivated grassland) in the landscape increased (Figure 2a,b). Generalized positive relationships of the proportion of semi-natural habitats in the landscape with bird abundance and species richness were also found for overall and forest and ecotone species both, in Castilla-La Mancha (Figures 4a,b) and Ebro regions (Figures 5a,b). However, in Castilla-La Mancha the abundance of foraging open land birds decreased as semi-natural habitats enlarged, while in the Ebro region the abundance of open land foraging and marginally

breeding birds increased (Figure 2a,b). In winter, semi-natural habitats within plots were represented by shrub land. Overall and forest and ecotone bird species richness increased with proportion of shrub land in plots in the whole study area (Figure 2c) and in the Ebro region (Figure 5c). However, we found negative relationships between this habitat component and the abundance of overall, forest and ecotone, and marginally open land birds in the whole study area (Figure 2c), as well as in Castilla y León (Figure 3c) and Ebro regions (Figure 5c).

3.3.2. Productive components

Fallow land showed generalized positive relationships with bird diversity in the whole study area in spring. Abundance and marginally richness of overall foraging bird species, as well as richness of forest and ecotone foraging bird species increased with the proportion of fallow land in the landscape (Figure 2a). Abundance of open land foraging birds also increased with fallow land in Castilla y León (Figure 3a) and Ebro regions (Figure 5a). Fallow land was especially relevant in Castilla y León, where the abundance and richness of overall and forest and ecotone breeding birds and the abundance of forest and ecotone foraging birds increased as its proportion in the landscape grew (Figure 3a,b). In winter, the proportion of fallow within plots also showed general positive relationships with the abundance of overall and open land birds (Figure 2c). In Castilla-La Mancha, in addition, the abundance of forest and ecotone birds increased with fallow land (Figure 4c). In the Ebro region, the abundance of open land birds increased, while the abundance of overall and forest and ecotone birds decreased with the proportion of fallow land (Figure 5c).

Nitrogen-fixing (legume) crops had overall positive relationships with bird abundance in spring. Abundance of overall, open land and forest and ecotone foraging birds increased with the proportion of these crops in the landscape, both in the whole study area and in the

three agricultural regions individually (Figures 2a-5a), but in the case of forest and ecotone foraging birds in Castilla-La Mancha (Figure 4a). Additional positive relationships with legume crops were found for the abundance and richness of forest and ecotone breeding birds in Castilla y León (Figure 3b) and Ebro regions (Figure 5b). In winter, however, most relationships with legume crops were negative in all the agricultural regions as a whole and individually, i.e., for the abundance of overall, open land, and forest and ecotone birds (Figures 2c-5c), but a positive relationship with the abundance of open land birds in Castilla y León (Figure 3c).

Conversely, the proportion of cereal crops within plots in winter presented positive relationships with the abundance of overall, open land, as well as forest an ecotone bird species in the whole study area (Figure 2c). In Castilla-La Mancha, these positive relationships were found for overall and forest and ecotone birds, but turned negative for open land birds (Figure 4c). The abundance of overall and forest and ecotone birds in winter also decreased as the proportion of cereal crop within plots grew in Castilla León (Figure 3c) and in the Ebro region (Figure 5c), while the abundance of open land birds increased, only in the latter.

The proportion of permanent crops in the landscape showed positive relationships with the abundance of overall foraging bird species, and marginally with the richness of overall and forest and ecotone foraging species in the whole study area in spring (Figure 2a). In Castilla y León, however, the abundance of overall, open land and forest and ecotone foraging birds decreased as the proportion of permanent crops in the landscape increased (Figure 3a). In Castilla-La Mancha the abundance of open land foraging birds decreased while the abundance of forest and ecotone foraging birds increased as the proportion of permanent crops in the landscape increased with permanent crops (Figure 4a). Last, in the Ebro region,

the abundance and richness of overall and open land breeding birds increased with permanent crops (Figure 5b).

Richness of herbaceous crops, considered either in the landscape (in spring) or within plots (in winter), showed generalized positive relationships with bird diversity (Figure 2). This was especially true in the Ebro region, where it benefitted overall, open land, as well as forest and ecotone bird species, both foraging and breeding (Figure 5a,b). Crop richness within plots also benefitted the abundance of all groups of birds in Castilla y León in winter (Figure 3c). However, in spring herbaceous crops' richness in the landscape presented mixed relationships with diversity in this region (i.e., positive with overall and forest and ecotone foraging bird species richness, and negative with overall and open land foraging bird abundance; Figure 3a). Last, in Castilla-La Mancha, abundance of overall and forest and ecotone foraging birds in spring also increased with crop richness in the landscape (Figure 4a), but in winter abundance and richness of overall and forest and ecotone bird species decreased with crop richness within plots (Figure 4c).

4. Discussion

Overall, bird diversity in Spanish cereal croplands was extensively affected by AES application and by habitat indicators linked to other CAP conservation tools both, within plots and most of all in the surrounding landscape. Most effects of local factors (i.e., AES application and habitat configuration and composition within plots) were found for foraging and wintering birds, particularly on their abundance (Figures 2 – 5; Appendix E). In contrast, species richness and abundance of breeding birds were almost exclusively affected by habitat configuration and composition in the surrounding landscape (Figures 2b-5b; see Moreira et al., 2005 for similar results for wintering bird assemblages in Portuguese grasslands).

Interestingly, our results indicate that, although local farm management (including AES and greening and cross-compliance measures) may promote the presence of birds locally, habitat configuration and composition in the surrounding landscapes are the determining factors for the establishment of bird territories in farmland. These results also support the hypothesis that mobile organisms with large home ranges, such as birds, tend to be conditioned most by factors acting at wider spatial scales (landscape or regional, rather than local factors; Concepción and Díaz, 2011). CAP conservation tools should then focus on managing habitat configuration and composition at such wider landscape scales. Our results also evince a great variation in the capability of the different CAP conservation tools to support bird diversity among regions and groups of birds, as detailed in the following sections.

4.1. Local management (AES)

As expected, AES benefitted most target open land birds, enhancing not only the presence of foraging and wintering birds but also the number of territories where applied (Figure 2). Nonetheless, AES also benefitted the presence of forest and ecotone birds, and consequently overall bird diversity. It is then possible to coordinate the preservation of specific conservation targets with overall diversity in case that target and non-target organisms share some requirements or conservation measures provide complementary resources for the latter (Concepción and Díaz, 2010; Moreira et al., 2005; Reino et al., 2009).

Particular prescriptions included in AES in each region most likely underlie their varying benefits for birds. Highest effectiveness of AES in Castilla y León is probably due to the fact that most prescriptions were related to land-use or habitat management, rather than to crop management itself (Díaz et al., 2012; See Appendix B for a list of AES prescriptions per study area). AES likely supported complementary habitats for a variety of birds in this region

(i.e., overall and open land species in spring, and forest and ecotone species during the winter following its application). However, AES prescriptions were almost identical in Castilla-La Mancha, where they resulted ineffective. These differences could in turn be due to differences in regional species pools between the two areas (Díaz and Concepción, 2016). AES prescriptions focused on the promotion of productive habitats (e.g., fallow land and legume crops) can be expected to be highly effective in Castilla y León, where open land birds clearly prevailed. In Castilla-La Mancha, though open land birds' occurrences were still high, forest and ecotone species increased their representation. Hence, a greater dependence of overall birds on semi-natural habitats, as also evince our results, may limit or constraint the effectiveness of AES focused most on productive habitats' management. In addition, our results emphasize that even the same group of organisms (i.e., open land birds) may have different responses to similar prescriptions, depending on the regional context. In Castilla-La Mancha in fact AES resulted ineffective not only for overall, but also for open-land birds. Higher landscape complexity in Castilla-La Mancha (especially in terms of proportion of semi-natural habitats in the landscape, with ca. 7.5 % on average compared to less than 2 % in Castilla y León; Appendix D) is likely constraining AES effectiveness in this region, where in-field diversity saturation threshold would have been reached and no further diversity enhancement due to extensive local management could be expected (Concepción et al., 2012, 2008).

4.2. Local habitat and landscape configuration

4.2.1. Patches

Overall, the maintenance of small field sizes seems to enhance bird diversity in Spanish cereal systems. In spring, we found consistent negative effects of average field size within plots on

bird diversity as expected (Fahrig et al., 2015, 2011). This was especially true for forest and ecotone birds that are supposed to benefit from fine-grained landscapes (Gabriel et al., 2010), and in the Ebro region (including the finest-grained landscapes, see Appendix D), where reduced average field size in plots favoured all bird groups in spring and winter. However, our results in Castilla-La Mancha and Castilla y León indicate the preference of wintering birds, especially open land species, for larger field sizes (Pickett and Siriwardena, 2011). This is likely related to a higher availability of resources provided by productive habitats in larger fields during winter (i.e., cereals, legumes or fallow land), which open land birds closely rely on (Morales et al., 2015; Moreira et al., 2005; Robleño et al., 2017; Suárez et al., 2004).

At the landscape scale, contrasting habitat requirements of open land *vs.* forest and ecotone birds became more evident, emphasizing the difficulties of making general policy recommendations and the need of carefully considering conservation targets' requirements in a regional context (Díaz and Concepción, 2016). Preventing field size enlargement at landscape scale is particularly recommendable in the Ebro region, where overall and forest and ecotone birds, which represent an important part of the regional species pool (see Appendix C), benefitted from reduced field sizes. Opposite, this measure does not seem so necessary in Castilla y León region (characterized by opener landscapes), where target open land birds that benefitted from large field sizes dominate the regional species pool.

4.2.2. Linear elements

Overall, semi-natural boundaries benefitted farmland bird diversity (Figure 2), though we also evinced highly variable responses of open land *vs.* forest and ecotone birds to these elements between regions, seasons and spatial scales as expected (Concepción and Díaz, 2010; Moreira et al., 2005; Reino et al., 2009). Semi-natural boundaries seem to constitute relevant

landscape connectivity features at the landscape scale for the maintenance of the regional species pool (i.e., supporting especially the presence of forest and ecotone bird species), as well as important winter habitats within farms for all group of birds in Castilla y León. Supporting the maintenance of semi-natural boundaries between, but not within farms to avoid negative border effects of these elements between more suitable open habitats during spring, seems to be a suitable prescription for open agricultural landscapes in this region.

In finer-grained landscapes of the Ebro region, in contrast, maintenance of semi-natural boundaries between fields within farms seems an appropriate conservation measure. However, although open land birds might benefit from semi-natural margins at local scales, its proliferation at landscape scale, though positive for forest and ecotone birds, is likely detrimental for the first group of birds, which still rely on open areas (Concepción and Díaz, 2011, 2010; Pickett and Siriwardena, 2011). Likewise, in Castilla-La Mancha, promoting the maintenance of existing semi-natural margins between fields seem appropriate measures. However, the creation of additional margins is likely to entail increasing borders rather than connectivity features for specialist open land birds, and thus may be detrimental.

4.3. Local habitat and landscape composition

4.3.1. Semi-natural components

As expected, we found general positive effects of semi-natural habitats in the landscape on bird diversity in spring (Figure 2; Pe'er et al., 2014; Underwood and Tucker, 2016), which were especially evident for forest and ecotone birds (Concepción and Díaz, 2010; Reino et al., 2009). The conservation of remnants of semi-natural habitats at landscape scale (including grass-, shrub- and woodlands) is especially recommendable in the Ebro region where, besides forest and ecotone birds predominated, these habitats benefitted all groups of birds, including

open land species in spring (Figure 5). This measure could also be implemented in Castilla-La Mancha, where the proportion of semi-natural habitats in the landscape benefitted overall, as well as forest and ecotone bird species in spring. However, it may result negative for open land birds, whose abundance decreased as the proportion of semi-natural habitats in the landscape grew (Figure 4). In winter, the benefits for bird diversity of increasing the amount of semi-natural habitats within plots (including only shrub land in this case)were not so evident. In fact, relationships with overall and even forest and ecotone bird diversity were mixed in the Ebro region (i.e., positive for species richness but negative for abundance; Figure 5c), or directly negative in Castilla y León (Figure 3c). These results point at the need of preventing farm abandonment and promoting winter productive covers, especially in regions like Castilla y León where farmland prevails, to ensure resource availability for a variety of birds during this season (Morales et al., 2015; Moreira et al., 2005; Suárez et al., 2004).

4.3.2. Productive components

Our results in general show that promoting certain productive habitats may benefit bird diversity in Spanish cereal systems (Figure 2). This was especially evident for open land birds, but also for forest and ecotone birds, probably due to the variety of complementary resources that these habitats provide to birds (Concepción and Díaz, 2010; Morales et al., 2015; Moreira et al., 2005; Robleño et al., 2017; Suárez et al., 2004). We yet found considerable differences in the effects of productive habitats on bird diversity between seasons and regions that should be considered before promoting certain crops or diversification measures.

In Castilla y León, promoting fallow land and legume crops that benefitted overall and forest and ecotone birds would be recommendable, particularly in spring (Figure 3a,b). In winter, preventing land abandonment and supporting crop diversification through the promotion not only of winter cereals, but also legume crops and fallow land, would benefit open land as well as forest and ecotone birds (Figure 3c). In Castilla-La Mancha in spring, both open land and forest and ecotone birds would benefit from crop diversification, while open land birds would additionally benefit from legume crops (Figure 4a). In winter, however, crop diversification resulted negative, particularly for forest and ecotone birds, like did legume crops for open land birds. Promoting fallow land that benefitted overall and forest and ecotone birds, would be instead more appropriate (Figure 4c). In the Ebro region, crop diversification is especially recommendable to favour open land birds in spring, as well as overall and forest and ecotone birds, both in spring and winter (Figure 5). Legume crops could be promoted in spring to benefit overall and forest and ecotone bird diversity. However, in winter their effects for all bird groups turned negative. Then, fallow land, which also benefitted bird abundance of all groups in spring, or cereal crops, seem better options, especially for open land birds. Regional differences in the effects of productive habitats on bird diversity were especially evident for permanent crops. Their promotion would only be recommendable in the Ebro region, where permanent crops benefitted overall and open land birds (Figure 5). On the contrary, in Castilla y León negative relationships with these crops prevailed for all groups of birds (either overall, open land or forest and ecotone; Figure 3), and mixed effects were found in Castilla-La Mancha (i.e., negative for open land species and mixed for forest and ecotone birds; Figure 4).

5. Conclusions

Our results point at the potential of measures focused on land-use management, both of semi-natural and productive habitat components, at farm and especially landscape scale for promoting farmland bird conservation in Spanish dry cereal croplands. Our results also highlight the need for regionally-target orientated conservation measures (see Table 2 for specific policy recommendation for farmland bird conservation in the three agricultural regions considered in this study). These measures could be assembled in the new CAP by means of regionally-adapted compulsory prescriptions applied throughout the agricultural landscape (i.e., advanced environmental conditionality likely replacing cross-compliance and greening). In combination, more specific and regionally-targeted voluntary measures (i.e., new eco-schemes and AES) could be designed according to the idiosyncrasy of each agricultural region in a way that ensure enough uptake among farmers to have impact on habitat configuration and composition at landscape scale. The high variability in our results evinces the difficulties of predicting the actual benefits for biodiversity of distinct conservation measures in particular cases. Therefore, performance evaluation and subsequent adaptation of management based on the results of such evaluation ought to accompany the implementation of CAP conservation tools in order to enhance their ecological success over time.

Table 2. Policy recommendations for the conservation of farmland birds in Spanish dry cereal croplands in the next CAP framework.

Compulsory measures (advanced environmental conditionality)
○ Prevent field size enlargement ○ Maintenance of existing semi-natural boundaries ○ Maintenance of remnants of semi-natural habitats
Voluntary measures (AES + eco-schemes)
• **Ebro basin (north-east Spain):** ○ Legume (N-fixing) crops (spring) ○ Crop diversification (spring and winter) ○ Fallow land (winter) ○ Permanent crops
• **Castilla y León (north-central Spain):** ○ Legume (N-fixing) crops (spring) ○ Fallow land (spring and winter) ○ Diversification of winter covers (including fallow land, legume and cereal crops)
• **Castilla-La Mancha (south-central Spain):** ○ Legume (N-fixing) crops (spring) ○ Crop diversification (spring) ○ Fallow land (winter)

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Author contributions

EDC and MD designed the study. MD coordinated research execution. EDC analysed the data and wrote the original draft. EDC and MD contributed substantially to write the final content of the manuscript.

Data accessibility

The data supporting the results will be archived, should the manuscript be accepted.

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Supplementary material:

Appendix A: Summary of prescriptions to qualify for "greening" payment of the CAP.

Appendix B: Prescriptions included in AES applied in the different study areas considered in this study.

Appendix C: Total number of individuals of bird species found in study plots (12.5 ha) of the different agricultural regions and survey seasons considered in this study.

Appendix D: Mean values (AVG) and standard deviations (SD) of configuration and composition metrics of local habitat (12.5 ha plots) and surrounding landscape (500-m radius buffers) for the different agricultural regions considered in this study.

Appendix E. Results of generalized linear mixed models (GLMMs) testing the effects of local management (AES *vs.* conventional), local habitat (12.5 ha plots) and surrounding landscape (500 m radius buffers) configuration and composition on bird diversity in the whole study area and the different agricultural regions and survey seasons considered in this study.

Appendix F: Detailed results and R code of generalized linear mixed models (GLMMs) testing the effects of the whole set of explanatory parameters on bird diversity in the whole study area and the different agricultural regions and survey seasons considered in this study, as well as the interactions between the factor agricultural region and the rest of predictors.