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Local improvement of skylark and corn bunting population trends on intensive arable landscape: a case study of the conservation tool Natura 2000

S. Brodier[1,2]*, S. Augiron[2]*, T. Cornulier[2,3] & V. Bretagnolle[2]

1 Centre Ornithologique Lorrain, Lay-Saint-Christophe, France
2 Centre d'Etudes Biologiques de Chizé, Beauvoir-sur-Niort, France
3 Institute for Biological and Environmental Sciences, University of Aberdeen, Aberdeen, UK

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Correspondence
Vincent Bretagnolle, Centre d'Etudes Biologiques de Chizé-CNRS, Beauvoir-sur-Niort 79360, France. Tel: +33 549 097817; Fax: +33 549 096526
Email: breta@cebc.cnrs.fr

*These authors contributed equally to this work.

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Abstract

For the past 20 years, different policy and regulatory tools such as the agri-environment schemes (AES) and the Natura 2000 network have been used in Europe to halt the ongoing decline of farmland birds resulting from agricultural intensification. Despite their wide implementation, bird populations are still declining at national and European scales, thus questioning the effectiveness of these schemes. Here, we examined the impact of the designation in 2004 of a Special Protection Area (SPA) for the little bustard on the local trends of two non-targeted, common but declining farmland birds, the skylark and the corn bunting, in an intensive arable landscape of western France. From 1996 to 2012, trends in skylark presence or abundance decreased whereas trends in corn bunting abundance first decreased and then showed a recovery; the trends differed between outside and inside the SPA. Outside the SPA and consistently with trends at the national and European scales, skylark abundance sharply decreased whereas corn bunting abundance first decreased and then stabilized or even slightly increased. Within the SPA, the skylark declined less, and the corn bunting abundance increased at a faster rate than outside. Our results suggest that the implementation of a SPA in this arable landscape had a positive impact on these two farmland passerines, at least for corn buntings, for which the implementation of AES clearly improved habitat. Our results also suggest that the extensive implementation of SPAs may have had a positive impact on bird population trends in farmlands at a regional level, where *c.* 150 000 ha (15–20% of total arable landscape) have been designated since 2004. However, the SPA network (within Natura 2000) currently covers a mere 3.7% of French arable landscape, and it is therefore no surprise that specialist birds in farmland are still declining nationally.

Introduction

In just four centuries, more than 80% of grasslands, savannas and scrublands have been converted and managed for human activities, while in the same time land used for agriculture and urban settlements increased from 5 to 39% of total ice-free land area (Ellis *et al*., 2010). Agricultural intensification within the last 50 years is now recognized as the main driver of the ongoing decline of about half of the farmland bird species across Europe (Donald, Green & Heath, 2001; Donald *et al*., 2006; Wilson, Evans & Grice, 2010). The exact causes of this major decline are multiple and act both at field and landscape scales (see Newton, 2004 for a review). In particular, increased use of pesticides (Geiger *et al*., 2010) and loss of habitat heterogeneity (Benton, Vickery & Wilson, 2003) are thought to have reduced the availability of both nesting and wintering habitats as well as food resources.

To counteract the negative effects of modern agriculture, two major conservation tools have been used in Europe over the last 20 years, including a range of more or less specific agri-environment schemes (AES; Kleijn & Sutherland, 2003; Vickery *et al*., 2004) and the generic Natura 2000 ecological network (Ostermann, 1998). AES form an agricultural policy instrument that directly encourages farmers to adopt a wide range of environmentally friendly practices through financial incentives. In contrast, the Natura 2000 network is based on legislation. Its core ambition is to protect endangered habitats and species through the designation of Special Protection Areas (SPAs) and Special Areas of Conservation (SACs) under the provisions of, respectively, the Birds Directive and the Habitat Directive (Council Directive

79/409/EEC and 92/43/CEE). Natura 2000 sites now cover 80 million ha of terrestrial habitats [i.e. 19% of the European Union (EU) territory; Boitier, 2011] and have become the largest network of protected areas in the world (Sundseth & Creed, 2008). Arable landscapes represent only a small portion of the French Natura 2000 network. Indeed, arable landscapes do not usually qualify for SAC status as they generally lack species or habitats listed under the Habitat Directive. However, the presence of one or several endangered species from Annex I of the Bird Directive may lead to SPA designations and, therefore, integration within the Natura 2000 network. The French system gives SPAs a priority status for the implementation of agri-environment measures. SPAs are therefore more likely to concentrate a high level of AES and to be more effective in delivering conservation benefits.

AES have in many cases proved to be effective at least locally (e.g. Peach *et al.*, 2001; Bretagnolle *et al.*, 2011; Perkins *et al.*, 2011). However, declines are still observed in farmland birds across Europe at the same rate (Voříšek *et al.*, 2010) even in countries in which some of the most significant conservation efforts were made over the last 10 years (e.g. UK; Davey *et al.*, 2010; DEFRA, 2013). As a consequence, both the effects of AES or Natura 2000, and the understanding of the causal links between agricultural changes and farmland bird declines have been challenged (Kleijn & Sutherland, 2003; Kleijn *et al.*, 2009, 2011; Wretenberg, Pärt & Berg, 2010). For instance, Donald *et al.* (2001) found that farmland birds declined more in Western than Eastern Europe, but that these trends were unrelated to the level of farmland under agri-environment prescriptions (Donald *et al.*, 2006), perhaps because the latter also included subsidies that were not designed with biodiversity benefits in mind. Similarly, Danish populations of farmland birds remained fairly stable despite agricultural intensification during the 1980s (Fox, 2004), whereas Swedish farmland birds decreased as much as in England despite a lower degree of agricultural intensification (Wretenberg *et al.*, 2006). These paradoxes may be apparent; in the latter case for instance, northern breeding birds may share the same intensified wintering areas. Unfortunately, most of the available studies on the subject either consist in large-scale monitoring on the one hand or in detailed mechanistic and ecological studies at the level of small sites on the other hand. Long-term studies at the intermediate regional scales at which Natura 2000 is actually implemented are however still lacking.

The skylark *Alauda arvensis* and the corn bunting *Miliaria calandra* are two common and widespread farmland birds, typically associated with lowland arable agriculture, that declined strongly in Europe over the last 30 years (46% for skylark and 78% for corn bunting; PECBMS, 2010), as well as in France (22 and 13%, respectively, between 1989 and 2009; CRBPO, 2011). Several ecological studies, mostly conducted in the UK, support the evidence that recent changes in farming practices led to declines in skylark populations (Wilson *et al.*, 1997; Chamberlain *et al.*, 1999; Donald, 2004) and corn buntings (Donald, 1997; Brickle *et al.*, 2000; Stoate, Borralho & Arauja, 2000; Wilson *et al.*, 2007) through a combination of factors affecting both survival and productivity. Agri-environment measures were implemented for both species in the UK, with demonstrated positive responses locally (Morris *et al.*, 2004; Smith *et al.*, 2009; Perkins *et al.*, 2011; Setchfield *et al.*, 2012), but the two species continue to decline at the UK level (Eaton *et al.*, 2012).

In this study, we assess evidence for an effect of the designation of a SPA which was dedicated to the little bustard *Tetrax tetrax* and other Annex I species, on species that were not targeted because they do not belong to Annex I (namely skylarks and corn buntings). The latter were monitored since 1996 on a 430-km^2 study site, almost half of which was designated as a Natura 2000 site in 2004, providing a landscape-scale quasi-experiment with before-after in addition to in-out contrasts (Kleijn & Sutherland, 2003). Conservation management targeted towards little bustards and implemented through AES mostly consisted in the provision and extensive management of grassland (hay meadows and alfalfa, with limited fertilization and optional delayed mowing) in an open arable landscape. These measures contributed to the reversal of the decline of the bustards by increasing the availability of rare, food-rich breeding habitats (Bretagnolle *et al.*, 2011). Despite their different ecological requirements and although not specifically targeted, skylarks and corn buntings may also have benefited from the SPA designation through the general compliance with Natura 2000 regulations, and/or through the implementation of AES (see Table 1) targeted for little bustard. Skylarks require different habitats for early and late nesting, especially in arable land where the vegetation structure of winter cereals is rapidly becoming unsuitable (Wilson *et al.*, 1997). Indeed, the diversity of crops available has been positively related to the breeding densities of skylarks (Chamberlain *et al.*, 1999; Chamberlain & Gregory, 1999). Corn buntings may benefit from delayed mowing because late breeders are particularly sensitive to early cutting for silage, and to harvesting (Crick *et al.*, 1994; Brickle *et al.*, 2000; Table 1). In both species, the increase of invertebrate resources resulting from limiting chemical inputs may improve breeding success (Brickle *et al.*, 2000; Henderson *et al.*, 2009). Whether designation of SPA and/or the implementation of AES targeted to other species has had any effect on non-targeted species has important implications for future conservation managements. Here, we expect

(1) that the SPA designation in 2004 had a positive effect on the population trends of these non-target species,

(2) that temporal or spatial changes in habitat availability, induced or not by AES, partly explained these trends, and

(3) that the trends differed according to the conservation tools applied, and to the scale considered (within and outside the SPA, at regional, national and European scales).

Materials and methods

Study area

The study was carried out in the *Zone Atellier* '*Plaine & Val de Sèvre*' (south of *Département des Deux-Sèvres*), in the

Table 1 Local AES and their expected benefits for skylarks *Alauda arvensis* and corn buntings *Miliaria calandra*

Type of AES	AES category	Main aim of AES	Expected benefits for skylarks and corn buntings	Source for skylarks	Source for corn buntings	Area under contract (ha)
Reduction of herbicides (RH)	AES 'arable'	Improvements of water quality and food availability	Improving food resources	Boatman *et al*., 2004; Henderson *et al*., 2009	Donald & Forrest, 1995; Brickle *et al*., 2000; Boatman *et al*., 2004	336
Reduction of fertilizers (RF)						1588
Combined RH + RF						1286
No tillage				Cunningham *et al*., 2005; Field *et al*., 2007		355
Organic farming		Improvements of habitat and water quality, and food availability	Improving food resources and breeding habitat quality	Wilson *et al*., 1997; Kragten *et al*., 2008		707
Arable reversion to grassland	AES 'grassland'	Increase of habitat heterogeneity	Improvement of breeding habitat quality and food resources	Chamberlain *et al*., 1999; Eraud & Boutin, 2002; Kragten *et al*., 2008; Henderson *et al*., 2012	Brickle *et al*., 2000; Fox & Heldbjerg, 2008	125
Arable reversion to alfalfa						188
Extensive management of grassland						813
Arable reversion to alfalfa + delayed cutting		Increase of safe nesting sites	Improvement of nesting success	Poulsen *et al*., 1998; Buckingham *et al*., 2011	Brickle & Harper, 2002; Perkins *et al*., 2011	323
Improved set-aside + delayed cutting						293
Arable reversion to alfalfa + delayed cutting						242

AES, agri-environment schemes.

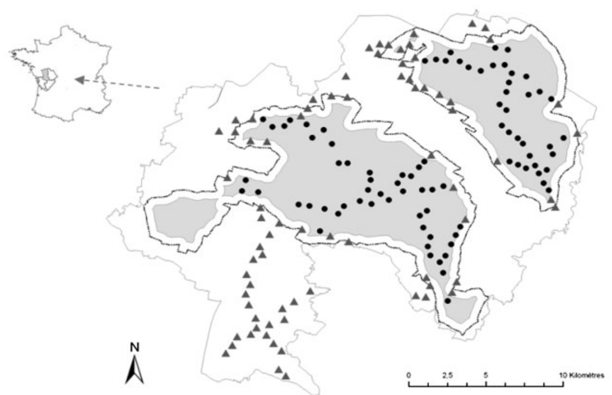

Figure 1 The limit of the study area in western France, a solid grey line. The Special Protection Area (SPA) 'Niort Sud-Est' is subdivided into two parts (hashed black line). The grey polygons represent the area for our study within the SPA. Black points represent count points included in the modified SPA delimitation (n = 84) and grey triangles, count points situated outside the SPA (n = 76).

arable lowland area of Niort-Brioux (46°15′N, 0°30′W; see Fig. 1 for the location). The study area is mostly dedicated to intensive cereal crop production but is characterized by relatively small fields (*c*. 4 ha on average), with 83% less than 5 ha, 13% being 5–10 ha and 4% more than 10 ha. In 2010, cereals accounted for 44% of the land use, grassland (including improved and unimproved hay meadows, alfalfa, pastures, set-aside and fallows) *c*. 15%, and spring-sown crops (mainly sunflower and maize) *c*. 24%. Hedgerows and trees are scarce. The presence of 17 Annex 1 species of the EU Bird Directive (notably the little bustard) led to the designation of half of the study area (207.6 km^2) as a SPA in 2004 (*Plaine de Niort Sud-Est*, FR5412007; Fig. 1).

Bird surveys

Bird populations were surveyed during the breeding season from 1996 onwards, using a network of 160 count points, a method particularly suitable for conspicuous species with a high level of singing activity like the corn bunting and the skylark (Bibby *et al*., 2000). The sampling was stratified into eight sub-sectors in order to ensure regular and tractable coverage of the study area. Count points were distributed along two crossing transects per sub-sector, each transect bearing 10 points separated by about 500 m (Fig. 1). Observation radius was restricted to 200 m from the observer to reduce any bias in detectability (e.g. observer or habitat mediated) and to avoid overlap of observations between two neighbouring points. All birds observed, as well as their behaviour (singing or not, flying or on the ground), were noted on a field map. Here, we restricted the analyses to singing birds, that is, territorial males. Rainfall, wind speed and cloud cover were also recorded.

Counts lasted 10 min per sampling point from 1996 to 2000, a duration that was reduced to 5 min from 2001 onwards with negligible loss of information on the probability of presence (see Bonthoux & Balent, 2012) or abundance (see table in Supporting Information Appendix S1). Counts were performed in the morning (from 7:00 to 11:00 AM), once during the breeding season until 2005 (between 20 April and 10 May). This period represents a good compromise for both species as skylarks have already begun their first nesting while most of the territories of male corn buntings are already established (Géroudet, 1998). Since 2006, an additional survey was carried out between 20 May and 10 June. In 1996, observers did not systematically record whether or not the birds were singing for skylarks. The number of skylarks singing in 1996 was back calculated using the relationship between the proportion of skylarks singing and the total number of skylarks observed per count point using data from other years. The relationship was estimated using a logistic generalized additive model (GAM) including the effect of wind, cloud cover and an additive smooth effect of the total number of skylarks observed during the count (Wood, 2006), including only points where at least one skylark had been observed. The explanatory variables accounted for 21.3% of the deviance in the proportion of singing birds ($R^2 = 0.22$; see Supporting Information Appendix S2).

AES were implemented mostly in the core of the SPA (see Bretagnolle *et al*., 2011). In our analysis we considered all the sampling points within 500 m of the border of the SPA as being 'outside' the SPA. This allowed us to focus on the comparison of areas with high versus low or no AES coverage. This treatment did not affect our results while making sample size more balanced (84 count points inside the SPA vs. 76 outside; Fig. 1).

Statistical analysis

We analysed presence-absence and abundance data for skylarks and corn buntings using GAMs ('mgcv 1.7-5' package for R 2.13.0; Wood, 2006). We used a binomial error structure for the presence-absence model and Poisson errors for the abundance model. The most parsimonious models were selected based on the corrected Akaike information criterion (AICc) (Burnham & Anderson, 2002). In addition, lack of spatial autocorrelation in the residuals of the final models was checked using a spline correlogram ('Gstat 2.4.4' package for R; Pebesma & Wesseling, 1998).

A first set of models was fitted in order to investigate potentially confounding effects on the proportion of birds present and singing such as weather covariates (wind speed, cloud cover, rain, mean temperature at the day of count and sum of rainfall over the 5 days before the count, assuming that singing activity increases after unfavourable weather), Julian date and time after sunrise. We included the rain covariate as a two-level factor, Julian date and time after sunrise as non-parametric splines, and all other covariates as linear effects. A model of confounding effects and including a 'year' covariate as fixed effect called 'baseline model' was selected by minimizing AICc and served as a basis for subsequent models. To correct for potential bias due to changes in the sampling conditions over time (weather, time, date),

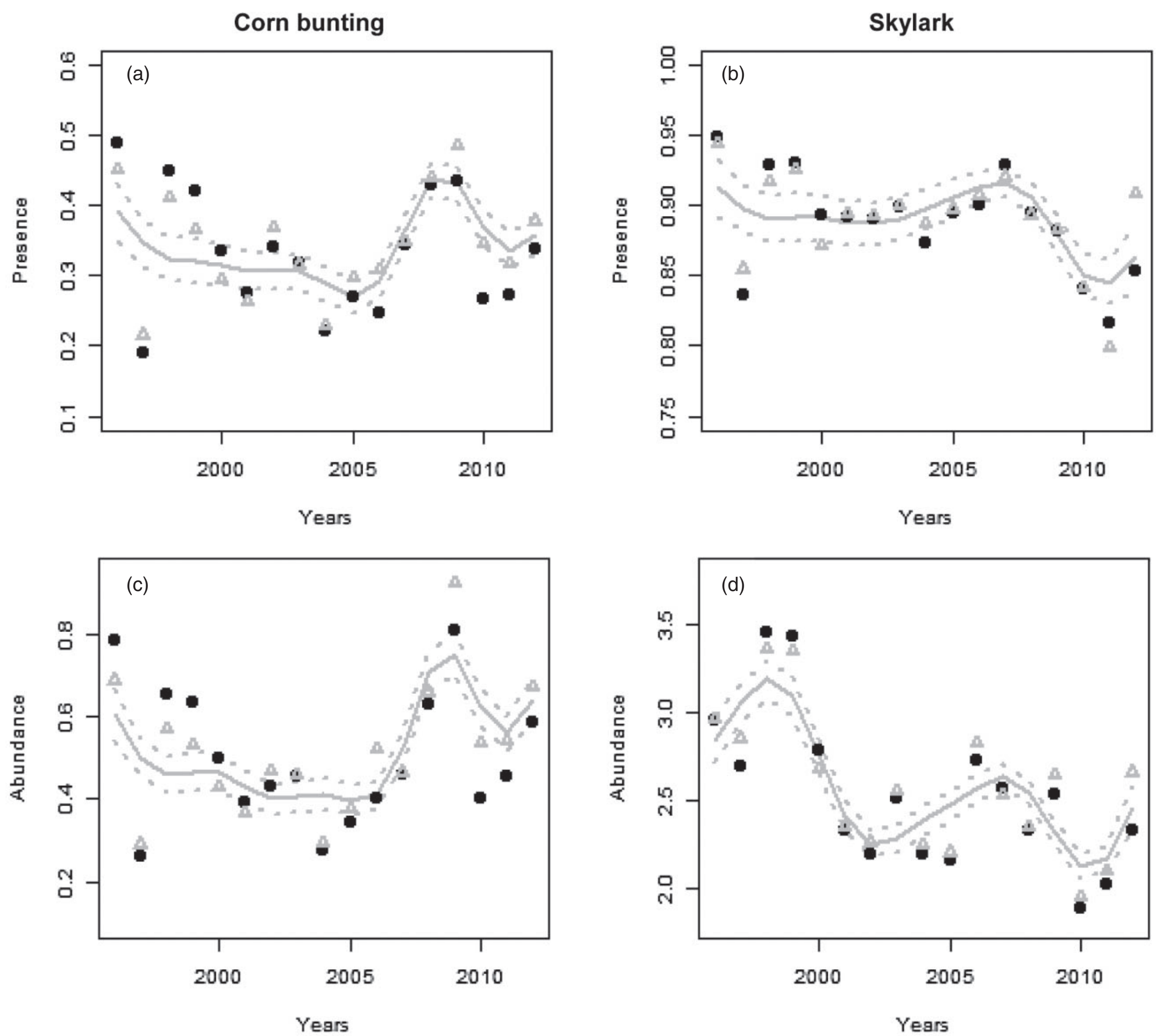

Figure 2 Plot of presence (i.e. probability of sighting at least one singing male per sampling point) and abundance (i.e. number of singing males per sampling point) for corn buntings (a and c) and skylarks (b and d) in our study area. Black dots represent the mean of the raw data. Grey triangles represent the predicted values from the generalized additive model (GAM) with a factor year added as a fixed effect. Solid grey lines represent the predicted values from the GAM model with year included as a spline effect. Grey dotted lines represent standard error.

we used the year-specific predictions of the baseline model for standardized conditions (see Fig. 2).

After inclusion of the relevant confounding covariates, we looked for temporal trends in the time series by replacing the year fixed effect by a spline function of year in the previous model, which we called 'trends model'. The number of degrees of freedom for the smoothing splines was selected automatically using the default generalized cross-validation procedure in mgcv (Wood, 2006) and was therefore only informed by the data. The spline analysis provides a convenient and flexible way of visualizing temporal trends in the presence or abundance but does not provide a straightforward formal test for local changes associated with SPA designation. Therefore, in addition to the spline analysis of the trends, we carried out a complementary analysis building upon the baseline model with removal of the spline year effect, to test for an effect of the SPA by comparing points falling within or outside the SPA (two modalities) and contrasting the years before or after the designation in 2004 (two modalities), which we called the 'SPA model'. We thus tested four models with and without interaction between the two, and assessed the degree of support for each model using AICc.

Finally, we included two habitat and two AES covariates in the 'SPA model' in order to assess whether the 'SPA effect' remained after taking into account broad land use changes and AES implementation. Wheat and 'grassland' (i.e. un-cropped habitat: pastures, meadows, set-aside and alfalfa) proportions within a 200-m radius around the sampling points (as for bird census) were selected as habitat categories. The proportion of each AES category was established according to the target habitat ('arable' vs. 'grassland'; see Table 1, summarizing the type and aim of the AES) within 200 m. This radius covers the range of most feeding trips in both corn buntings (Brickle *et al*., 2000) and skylarks (Eraud, 2002).

For trend analyses at higher spatial scales (regional, national and European), we compared trends visually because we did not have access to raw data.

Results

Smoothed trends in the time series for the whole study area, accounting for confounding covariates

Both weather, time of day and date covariates had effects on skylark and corn bunting presences and abundances. Five and two competing models, respectively, for skylark and corn bunting abundance, and 2–11 competing models, respectively, for skylark and corn bunting presence presented a ΔAICc value lower than 2. Despite the number of models, the time after sunrise and Julian date were selected in all models with a negative effect (time after sunrise non-significant for skylark presence). Wind and rain (the sum of precipitation 5 days before count) were selected in three models, with negative effect of wind on the presence and abundance of corn buntings (non-significant for skylark abundance), whereas rain had a significant positive effect on presence of corn buntings and on abundance of both species. Finally, cloud cover and mean temperature during the morning were selected in the best 'baseline model', with cloud having weakly positive or non-significant effects for skylark presence and abundance, and temperature a significantly positive effect on skylark presence and weakly positive for abundance.

Accounting for these confounding variables in the subsequent models allowed us to correct the raw data for differing sampling conditions over the season and between years, such as variations in the time window of the census from one year to another (Fig. 2a–d, compare corrected and uncorrected estimates). Figure 2 shows temporal trends for the whole area analysed using spline functions after accounting for confounding variables in the model. Corn bunting presence and abundance decreased between 1996 and 2004 before increasing afterwards, although with a sharp decrease in 2010 (Fig. 2a,c). Skylark presence remained stable with small oscillations between 1996 and 2009 and tended to decrease slightly since 2009 (Fig. 2b). Conversely, skylark abundance declined continuously from 1996 to 2012 (Fig. 2d). Overall, between 1996 and 2004, both species declined in abundance (by 30% in skylarks and 60% in corn buntings); after 2005, the decline continued in skylarks but stopped in corn buntings (Fig. 2).

Temporal effect of the designation and spatial effect of delineation of the SPA

The SPA was designated in 2004: we thus compared the mean of presence and abundance for both species before and after 2004, and within versus outside the SPA. We also tested the trends between counting points within versus outside the SPA using spline functions of year (see Fig. 3a,b for abundance).

For both species, presence and abundance values were higher within the SPA than outside. In particular, presence and abundance were higher within the future SPA, for abundance by 9 and 13% for skylarks and corn buntings, respectively, indicating an *a priori* effect of the designation site. Skylark presence declined in both parts, especially after 2006, but with greater fluctuations outside the SPA. Skylark abundance also declined in both parts, with oscillations, but the decline was smaller within the SPA (12% within vs. 19% outside, between 1996 and 2012; Fig. 3b). Corn bunting presence declined slightly between 1996 and 2004, and then remained stable or slightly decreased outside the SPA. Corn bunting abundance declined slightly between 1996 and 2005 and then increased at a faster rate within the SPA than outside (Fig. 3a).

Four statistical models [with additive and interactive effects between spatial (in/out) and temporal (before/after) processes] were evaluated for four variable responses (two species, two metrics; see Table 2). Overall, a consistent positive effect was found for points within the SPA and, to a lesser extent, for a change around the SPA designation in 2004. Out of the four models, the interactive effect was supported in three of them (except presence corn bunting model; Table 2), although not necessarily with the lowest AICc, indicating that SPA may have had both a spatial (delineation) and temporal (designation) effects. In addition and in both models of abundance, the difference in abundance increased after the SPA designation inside the SPA. It reached 17 and 24%, respectively, for skylarks and corn buntings, compared with the initial difference in abundance being 9 and 13%, respectively.

Are SPA effects a result of changes in landscape composition or of AES implementation?

We tested if the positive effect of SPA implementation on these birds could be explained by land use changes alone ('grassland' and 'wheat' proportion) and/or AES implementation since 2005 (proportion of AES 'grassland' and 'arable'). Wheat proportion increased significantly between the two periods, and was similar between outside and inside the SPA (Supporting Information Appendix S3). The proportion of grasslands increased significantly inside the SPA after the designation (+3.8%, $H = 29.91$, $P < 0.001$) but not

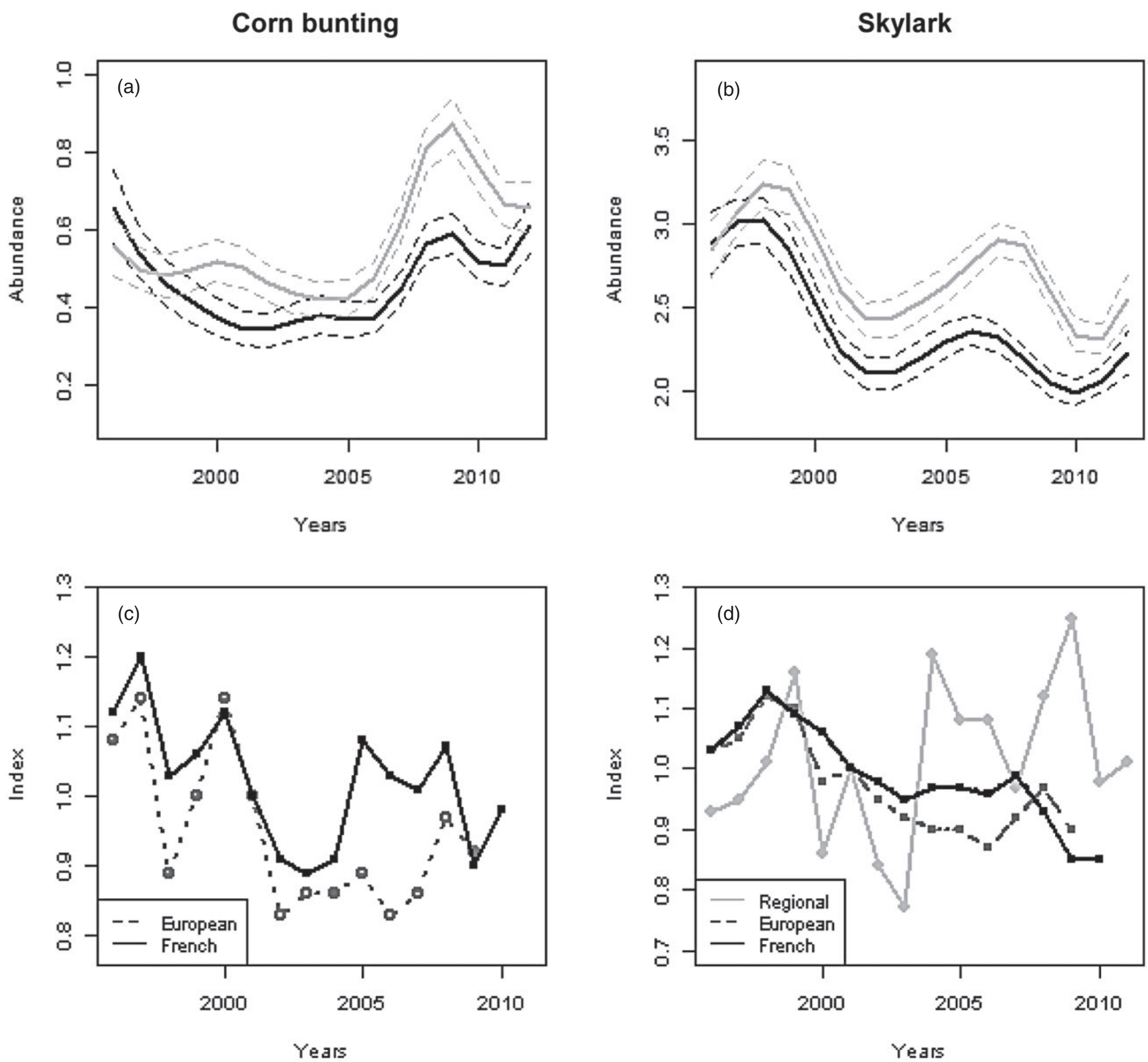

Figure 3 Plot of predicted values (mean ± standard error) from the generalized additive model for corn bunting (a) and skylark (b) abundance with one spline function of year for within (grey) and outside (black) the Special Protection Area comparison with corn bunting (c) and skylark (d) large-scale trends. European data were redrawn from European Bird Census Council web site, and French data were obtained from STOC (CRBPO-MNHN) national survey (see Jiguet *et al*., 2012). Both datasets were standardized to allow comparisons, and the index value of 2001 was arbitrarily set to 1. For the skylarks, trends from 46 regional road transects in Région Poitou-Charentes are also shown (see Eraud 2002 for methodology).

outside the SPA (+1.4%, H = 1.3, $P = 0.251$). This strong increase inside the SPA led to a significant difference in proportion, compared with outside the SPA after 2004 (after 2004 inside +3.3%, H = 38.8, $P < 0.001$). For both AES metrics, the mean proportion was higher within the SPA than outside, with a strong difference for the AES 'grassland' (5.1% ± 11.4 SD within; 0.6% ± 3.2 SD outside: Kruskal–Wallis test: H = 241.39, $P < 0.001$), less so for AES 'arable' (8.3% ± 17.2 SD within and 6.3% ± 16.2 SD outside; H = 23.23, $P < 0.001$).

Including landscape composition and AES covariates into the 'SPA model' improved the ΔAICc value by more than 2 for each response variable (see Supporting Information Appendix S4). In skylarks and in both presence and abundance models, two models including the proportion of wheat, grassland, 'grassland' AES and, alternatively, 'arable' AES or not had equal support. In addition, wheat proportion had a significant positive effect whereas the proportion of grassland and 'grassland' AES had a significant negative effect. Moreover, the proportion of 'arable' AES

Table 2 Spatial and temporal effects of SPA designation on corn bunting *Miliaria calandra* and skylark *Alauda arvensis* on presence and abundance, accounting for confounding variables (called 'baseline model'; see Materials and methods section)

Response variable	Covariates	d.f.	logLik	AICc	ΔAICc	Weight
Skylark (presence)	Baseline + SPA	9.45	−1355.94	2730.82	0.00	0.52
Skylark (presence)	Baseline + SPA × Periods	11.17	−1354.85	2732.13	1.31	0.27
Skylark (presence)	Baseline + SPA + Periods	10.41	−1355.89	2732.65	1.83	0.21
Skylark (presence)	Baseline + Periods	9.20	−1362.58	2743.61	12.79	0.00
Corn bunting (presence)	Baseline + SPA	10.23	−2363.97	4748.45	0.00	0.51
Corn bunting (presence)	Baseline + SPA + Periods	11.09	−2363.47	4749.20	0.75	0.35
Corn bunting (presence)	Baseline + SPA × Periods	12.09	−2363.47	4751.22	2.76	0.13
Corn bunting (presence)	Baseline + Periods	10.13	−2369.11	4758.53	10.08	0.00
Skylark (abundance)	Baseline + SPA × Periods	11.05	−7000.28	14 022.73	0.00	0.79
Skylark (abundance)	Baseline + SPA + Periods	9.92	−7002.75	14 025.41	2.68	0.21
Skylark (abundance)	Baseline + SPA	8.80	−7010.17	14 037.99	15.26	0.00
Skylark (abundance)	Baseline + Periods	8.97	−7029.08	14 076.16	53.43	0.00
Corn bunting (abundance)	Baseline + SPA + Periods	14.74	−3720.67	7470.95	0.00	0.51
Corn bunting (abundance)	Baseline + SPA × Periods	15.68	−3719.77	7471.04	0.09	0.48
Corn bunting (abundance)	Baseline + SPA	13.94	−3725.63	7479.24	8.29	0.01
Corn bunting (abundance)	Baseline + Periods	13.69	−3732.76	7493.00	22.05	0.00

'SPA' calls for spatial effect (i.e. inside vs. outside the SPA), whereas 'Period' calls for temporal effect (i.e. before vs. after the designation). The four possible models are compared (simple factor, additive and interaction between two factors). AICc values and Akaike weights for the models are presented. AICc, corrected Akaike information criterion; d.f., degrees of freedom; SPA, Special Protection Area.

had a negative (but non-significant) effect on abundance and presence.

For corn bunting abundance and presence, respectively, three and two competing models showed a ΔAICc value lower than 2. Overall, grassland had a significant positive effect on presence and abundance, whereas wheat had a negative (although non-significant) effect on abundance. The proportion of 'grassland' AES was selected in all presence and abundance models (with a significant positive effect). The proportion of 'arable' AES had a positive but non-significant effect on abundance.

Finally, the intrinsic positive SPA effect remained detectable after including landscape composition and AES covariates for all variable responses (skylark and corn bunting presence and abundance).

Comparison with trends at higher spatial scales

The skylarks and corn buntings have declined continuously at both European and national levels. In both species, national patterns are remarkably similar to European trends. For both the skylarks and corn buntings, the large-scale patterns, especially the national trends, are very similar to those observed in our study site outside the SPA. Trends within the SPA are comparatively more positive than national trends (Fig. 3), suggesting a local departure from larger scale patterns. Interestingly, skylark abundance is found to be stable or slightly increasing at a regional scale, especially so since 2003–2004 (Fig. 3d; data not available at this scale for the corn buntings).

Discussion

Population trends

The comparison of local and large-scale trends showed that the dynamics of the two species were similar between the parts of our study area outside the SPA and the national and European trends. The contrasting trends we found in our study area between within and outside the SPA and between periods form near-experimental evidence of the positive local effects of the SPA implementation on two non-targeted farmland specialist bird species. Skylarks and, to a lesser extent, corn buntings have globally declined over the last 16 years. However, within the SPA, skylark decline was less pronounced and corn buntings have increased at a faster rate since designation. Slightly higher initial bird abundances in the SPA (by about 10%) compared with outside suggest that the SPA was designated in an area with higher baseline densities of skylarks and corn buntings from the outset. Indeed, the limits of the SPA were drawn to include areas holding active or formerly active leks of the little bustard as well as several threatened farmland species from the Annex I of the Birds Directive, such as stone curlews *Burhinus oedicnemus* and Montagu's harriers *Circus pygargus*. This species community requires mixed farming systems with structurally diverse crop mosaics including arable spring-sown crops, non-crop habitat and/or perennial crops (Salamolard & Moreau, 1999; Green, Tyler & Bowden, 2000; Wolf *et al.*, 2001; Koks *et al.*, 2007). We could therefore expect that farmland specialist passerines that require several habitats for breeding and foraging through the annual cycle, including skylarks (Wilson *et al.*, 1997; Chamberlain *et al.*, 1999) and corn buntings (Gillings & Watts, 1997), were initially also more numerous within the designated area (see also Pellissier *et al.*, 2013). The fact that skylark and corn bunting trends differed between outside and within the SPA however suggests that an additional habitat improvement consecutive to the SPA designation occurred, rather than just an *a priori* delineation bias (abundance was around 20% higher in SPA than outside after designation). Moreover, it is likely that the conservation measures following the designation were particularly effective because our study site still held a relatively diversified crop mosaic and a high level of biodiversity (17 species of community interest are present, of which 6 with large numbers) (see Kleijn *et al.*, 2009; Whittingham, 2011). These results are in line with previous findings on the effect of SPAs on birds at the scale of Europe (Donald *et al.*, 2007) and on common birds species at the scale of France (Devictor *et al.*, 2007; Pellissier *et al.*, 2013), although these latter authors suggested that real conservation managements may be still too recent to have detectable effects on trends.

Interestingly, variations in bird presence over time inside and outside the SPA were relatively small compared with variations in abundance, suggesting that populations essentially responded by variation in local density rather than by the colonization/desertion of new/former areas. This may suggest a patchy distribution of habitat resources. However, the local decrease observed since 2009 remains surprising, in its intensity and because it the affected presence and abundance of both species both within the SPA and outside. A potential explanation lies in the severity of the winters in 2009–2010 and 2010–2011, with long periods of snow cover or sub-zero temperatures. This may have resulted in a high mortality of sedentary birds that would have seen their abundance reduced in the following breeding seasons (see, e.g. Cawthorne & Marchant, 1980). The weather hypothesis is locally supported by a similar strong decline in the same years in other resident or short-distance migrant species such as yellowhammers in contrast with long distance migrant ones, for example, yellow wagtail and warblers (V. Bretagnolle, unpubl. data). Alternatively, or in conjunction, rotational Common Agricultural Policy (CAP) set-asides were highly selected by farmland birds and notably skylarks (see, e.g. Gillings *et al.*, 2010); their discontinuation in 2008 at the national and European scales may also have had a negative impact on bird populations.

The increase in skylark abundance found at the regional scale of Poitou-Charentes is in sharp contrast with declines found at other scales (national, European and outside SPA). The Poitou-Charentes region has been subjected to a quantitatively high and unique implementation of SPA in arable areas since 2004 (eight SPAs, covering nearly 150 000 ha). This represents 15–20% of arable landscapes and 8% of the total area of the region. This extensive designation may have improved the regional trend, as happened in our study area.

SPA and habitat improvement

The most likely candidate for explaining an improvement of habitat quality within the SPA is the strong implementation, in its core, of AES aiming at improving breeding habitats for little bustards (see Bretagnolle *et al.*, 2011). AES were widely adopted by farmers (from only 580 ha contracted in 2005 to 9374 ha by 2011). This success led to a significant increase of the proportion of extensively managed grassland (especially alfalfa) in the SPA since 2005, after a 10-fold decline since the 1950s (V. Bretagnolle, unpubl. data). However, skylarks and corn buntings clearly differed in their response to landscape composition and AES metrics. Corn buntings were positively affected by grassland availability (local proportion of all grasslands within 200 m) and further by the low-intensity and/or wildlife-friendly management of grasslands (positive additive effect of ‘grassland’ AES) (see also Perkins *et al.*, 2011 and Davey *et al.*, 2010). Conversely, skylarks preferred wheat-dominated habitat, and their numbers responded negatively to both AES metrics tested here. This unexpected result may be explained by several facts. First, there is a strong heterogeneity in our broad categories for ‘grassland’ (which includes alfalfa, set-aside, pasture, cultivated grass, etc.) and for AES (fertilization limitation, safe nesting, etc.), which may have obscured the detection of more subtle relationships between skylark abundance and land use. Second, skylark habitat preferences may vary over time and spatial scale (Miguet, Gaucherel & Bretagnolle, 2013). Third, our analysis does not allow us to know if the population trends are related to higher habitat attractiveness, higher nesting success or higher winter survival. Overall, it is likely that AES options interact both spatially and temporally, thus having complex and variable effects on skylarks. Finer analyses of the relationships between specific practices and their effects on different bird species will be needed.

Conclusions

Our results suggest that the designation of a SPA in these arable lowlands had a local, positive impact on skylark and corn bunting trends. Moreover, a dense network of SPAs dedicated to arable landscape may have had a positive impact on skylark trends at the Poitou-Charentes regional scale. Whereas corn buntings appeared to have benefited from the increase in the amount of the rarer, grassland habitat and lowering the intensity of its management due to implementation of AES, no obvious positive effect of change in land use was identified for skylarks. Overall, our results confirm that conservation areas could constitute important spatial refuges for declining common species (Devictor *et al.*, 2007; Pellissier *et al.*, 2013). Finally, our study suggests that conservation actions may yield beneficial results at regional scales (Whittingham, 2007), and that the Natura 2000 network construction should be considered in regional conservation objectives (Louette *et al.*, 2011).

In contrast with the UK (Morris *et al.*, 2004; Perkins *et al.*, 2008, 2011), skylarks and corn buntings are not specifically targeted by AES in France because they are still common and widespread and/or because they have suffered comparatively smaller declines. Their populations are however still declining, perhaps at a greater pace as a result of the abolition of the CAP set-asides in 2008 (Gillings *et al.*, 2010). Extensive grassland provision above a critical threshold may represent a generic option to stop or slow down the negative trends of one or both of these species (Piha *et al.*, 2007; Fox & Heldbjerg, 2008; this study) and probably of many taxa in arable-dominated landscapes (see also Robinson, Wilson & Crick, 2001; Atkinson, Fuller & Vickery, 2002). There remains the challenge of making AES options attractive to farmers in areas where arable crops provide high financial return, and in the current context of increasing political pressure to produce more food.

At a national (as well as European) scale, economic incentives towards conservation management options in arable areas may still be too limited because they are generally geographically confined to priority sites (Natura 2000 and water protection zones), except for 'broad and shallow' schemes, which have shown limited evidence for a positive effect on biodiversity (e.g. Entry Level Stewardship in UK; see Davey *et al.*, 2010). Moreover, arable management options generally focus on field margins and/or on chemical inputs rather than on reversion from crops to grassland, largely because farmers favour the schemes that require the least modifications of their practices (Arnaud & Dupraz, 2006). However, our study provides indication that where EU Bird Directive species like the little bustards are present, they can represent an effective 'umbrella' species. Although the range of such species may be geographically limited, this strategy may be seen as a local complement to a broader land use strategy aiming at integrated development at the territorial scale.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Appendix S1. In order to evaluate the influence of the transition from 10 to 5 min on our abundance estimates, we used a network of 20 count points in 2002. All skylarks and corn buntings contacted were localized each minute to obtain cumulative curves of recorded birds. This protocol was repeated five times during the breeding season.
Appendix S2. Plot of the relationship estimated using a logistic GAM, between total skylarks observed and the proportion of skylarks singing.
Appendix S3. Differences in wheat and grassland proportion, between before-after the designation of the SPA (2004), inside versus outside, and differences in wheat and grassland proportion between inside and outside the SPA, before versus after 2004. Significant results are in bold characters.
Appendix S4. Model selection procedure with the inclusion of habitats (% Wheat and % Grassland) and AES (% arable AES and % of perennial AES) covariate to SPA model on corn buntings and skylarks on presence (binomial error) and abundance (Poisson error). AICc values, Akaike weights (w) for the models are presented.