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Long-term effectiveness of Natura 2000 network to protect biodiversity: a hint of optimism for common birds

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2 **optimism for common birds**

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13 ABSTRACT

14 The Natura 2000 protected area network (N2000), implemented under the Birds and Habitats
15 Directives (respectively, Special Protection Areas, SPA, and Special Areas of Conservation, SAC),
16 constitutes a key tool for the conservation of European biodiversity. To date, few studies have
17 looked at its long-term effect on biodiversity and even fewer on common species. Here, using
18 citizen science data, we investigated this effect on the temporal trends of widespread and common
19 bird species in France, over the period 2002-2016. We found results consistent with previous
20 findings demonstrating a significant decline of common bird populations in France. However, we
21 show that this decline is less steep within N2000 areas than outside, especially for farmland
22 specialists. While SPAs and SACs contribute to the overall effect on bird populations, SACs
23 contribute most to the less steep decline of farmland species within N2000 network. Despite
24 generally more diverse bird communities within N2000 areas, their designation has not prevented
25 their ongoing functional biotic homogenization. We conclude that, common bird species - not
26 directly targeted by the Directives - may have benefited from the N2000 protection or management
27 measures. However, the positive but limited effect of the N2000 network suggests that it is not able
28 to reverse negative population trends either because the land management or spatially extent are
29 insufficient. As such, we suggest that improving management plans, expanding existing PA,
30 establishing new ones, are the priority actions that may help improve N2000 effectiveness.

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36 ***Key Words***

37 Breeding Bird Survey; Community Changes; Citizen Science; EU Biodiversity Strategy; Long-term
38 monitoring; Population Trends; Protected Areas; Protection Regulations

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41 1. Introduction

42 Among several international initiatives which have attempted to coordinate action to halt or reverse
43 biodiversity loss, the most important was the Convention on Biological Diversity (CBD;
44 www.cbd.int), to which 196 nations are parties, and which the European Community ratified in
45 1993. The European Union's major contribution to respond to the CBD programme of work on
46 protected areas is the Natura 2000 (N2000) network. It aims to set up well-managed protected sites
47 in the whole European territory.

48 The N2000 network focuses on the conservation of specific species and habitats of
49 Community interest, but its target is wider : to contribute to ensuring biodiversity through the
50 conservation of natural habitats and of wild fauna and flora in the EU (European Commission,
51 2016). The N2000 network currently stretches over 18 % of the EU's land area. The N2000
52 network is regulated by two directives: following the Birds Directive of the European Union
53 (79/409/EC; Directive 2009/147/EC since 2009), Special Protection Areas (thereafter SPA) are
54 designated by Members States to protect rare and vulnerable birds, as listed in Annex I of the Birds
55 Directive, and regularly occurring migratory species. The identification and delimitation of SPAs
56 must be entirely based on scientific criteria (such as '1% of the population of listed vulnerable
57 species' or 'wetlands of international importance for migratory waterfowl'), and the Member States
58 must ensure that all the 'most suitable territories', both in number and surface area, are designated.
59 The other Natura 2000 areas are Special Areas of Conservation (thereafter SAC) which are defined
60 following the Habitats Directive of the European Union (92/43/EEC) to protect non-bird animals
61 and plant species and habitats listed in the Annexes I and II of this directive. The annual costs of
62 implementing the N2000 network were estimated as €5.8 billion per year for the 27 member states
63 (Gantioler et al., 2014). As a consequence it seems relevant to determine whether this investment in
64 the conservation and management of natural environments is effective. In addition, a good
65 understanding of how effective are the current biodiversity protection tools is a key element to
66 achieve the Aichi Targets, specifically Targets 11 (protected areas) and 12 (threatened species), and
67 Sustainable Development Goal 15 (terrestrial biodiversity) (Chape et al., 2005; Zafra-Calvo et al.,
68 2019).

69 Common species - those that are abundant and widespread (Gaston 2010) - although not
70 targeted for the designation of N2000 areas, are recognised as having a key role in ecosystem
71 functioning (Pigot et al., 2016). Rare birds are not the only ones that need protection, as the decline
72 in common and widespread species be more dramatic (Inger et al., 2015) and may have larger
73 impacts on ecosystems (Gaston, 2010). Birds associated with farmland habitats have been
74 particularly affected, as their populations have dropped by more than 50% in Europe since 1980
75 (see <https://pecbms.info/european-wild-bird-indicators-2018-update/>). And to date, no changes in

76 agricultural policies (e.g. UE CAP; see Pe'er et al., 2014) have been efficient at slowing down
77 farmland bird declines (Gregory et al., 2019). As such, it is of paramount importance to determine
78 whether the N2000 investment in the conservation and management of natural environments could
79 also benefit common biodiversity, in order to monitor and improve the effectiveness of billions of
80 euros needed annually for managing N2000 (Gantioler et al., 2014; Santana et al., 2014).

81 Assessments of the effectiveness of N2000 network have first relied on gap analysis,
82 evaluating how protected areas encompass targeted species distribution (Abellán and Sánchez-
83 Fernández, 2015; Hochkirch et al., 2013a; Kukkala et al., 2016; Maiorano et al., 2015; Trochet and
84 Schmeller, 2013). These studies mostly focus on species of “community interest”, but the suitability
85 of the network has also been assessed for species other than those for which the Natura 2000 sites
86 have been set-up. More recently, there have been several studies highlighting that the designation of
87 N2000 network is also benefiting non-targeted species (Devictor et al., 2007; Kerbiriou et al., 2018;
88 Lisón et al., 2015). Such studies are useful to assess the network suitability but they do not provide
89 any information on how effective it is in maintaining or restoring populations because they do not
90 consider temporal data (i.e. trends) and in/out comparisons. Several studies tested more complex
91 approaches to assess this effect. At the European level, Donald et al. (2007) compared Annex I and
92 non-Annex I bird species' trends in 1970-1990 and 1990-2000, and within and outside the EU,
93 showing positive effects for Annex I species. This work was confirmed by Sanderson et al. (2016)
94 using newer data and accounting for climate change effects. Some other studies compared trends
95 inside and outside Natura 2000 sites at national level, focusing on one Annex I species (Silva et al.,
96 2018) or on one site (Brodier et al., 2014; Santana et al., 2014). Although Brodier et al. (2014)
97 found positive impact of SPA locally in France, Silva et al. (2018) and Santana et al. (2014) found
98 mixed effects of SPAs in Portugal.

99 Fewer studies are available concerning common species. Also, they use general biodiversity
100 measures as do most studies evaluating conservation investments (Concepción et al., 2012; Santana
101 et al., 2014), even though evaluations should also consider indicators reflecting species assemblage
102 according to their functional traits (Princé and Jiguet, 2013). At a European level, work previously
103 showed that a greater number of common (non-targeted) species occur within N2000 network than
104 outside but that generalist bird species are underrepresented in the network because large parts of
105 their ranges lie within more intensively used areas (van der Sluis et al., 2016). In France, previous
106 findings highlighted that common bird species have actually benefited from the designation of
107 N2000 directed toward other target species (Devictor et al., 2007; Pellissier et al., 2013). Looking at
108 population trends, Pellissier et al. (2013) found identical trends in and out N2000 for specialist bird
109 species, and increase of generalists solely outside the N2000 network, and argued for the need of
110 longer time series. At a European level, Gamero et al. (2017) found that among the 39 farmland

111 bird species considered, Annex I species only had higher population growth rates with increasing
112 SPAs, indicating that SPAs may solely fulfill the main role they were designed for, with no positive
113 effect for the whole farmland bird community. Pellissier et al. (2020) found that only habitat
114 specialist birds, and especially woodland birds, had higher abundances in SPAs, so that land cover
115 may be a determinant of positive effects of the N2000 network. Faced with these sparse results,
116 questions remain as to whether the investment related to the N2000 network can have a broader
117 impact than on target species, i.e., on common bird populations and communities, over time and at
118 large scale.

119 Here, using long-term monitoring bird data, we investigated the effect of the protection
120 network on the temporal trends of the overall community of common breeding species, including
121 mostly non-targeted avian biodiversity, in France over the last fifteen years (period 2002-2016).
122 Relying on the French Breeding Bird Survey (FBBS) data, we tested the general hypothesis that
123 N2000 could benefit common bird populations and communities over time. Such citizen science
124 monitoring programs have already proved to be an efficient tool in assessing protected area
125 networks (e.g. North American Breeding Bird Survey: Cazalis et al., 2019; Pan-European Common
126 Bird Monitoring: Gamero et al., 2017; Pellissier et al., 2020; French Breeding Bird Survey:
127 Pellissier et al., 2013). Specifically, we aimed to (1) check the temporal trends of common breeding
128 bird populations and community structure inside and outside of the N2000 network, and (2)
129 compare the contribution of SPAs and SACs sites in the protection of common birds. As the FBBS
130 also provides monitoring data for some species listed in the Annex I of the Birds Directive, we also
131 aim to (3) specifically estimate the population trends of such targeted species.

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133

134 **2. Material and Methods**

135 *2.1. Bird data*

136 We used data collected during 2002-2016 by the FBBS, a standardised monitoring scheme in which
137 observers (volunteer ornithologists with acknowledged expertise) survey breeding birds in
138 randomly selected 2x2-km square (further named plot) by counting birds at 10 point counts (5 min
139 each) twice per spring. See Jiguet et al. (2012) and Appendix A1 for details.

140 From this dataset, we selected a total of 1918 BBS squares surveyed at least twice between
141 2002 and 2016. We focused our analysis on species with at least 100 occurrences during the survey
142 period, excluding waterbirds as wetlands are not efficiently sampled by the scheme. We obtained a
143 final subset of 162 species with complete trait information (Table A1), representing 99.4% of all
144 records. For each species, BBS plots where that species was never recorded during the survey
145 period and that were outside the species distribution range - as determined by the latest French Bird

146 Atlas (Issa and Muller, 2015) - were considered as true absences and removed from the dataset.
147 This was done to avoid the interpretation of the data from these plots as false absences of the
148 species (i.e. data recording the absence of a species where the species was potentially present),
149 which could create mis-interpretation of the results.

150 As a structured survey, the FBBS enforces a sampling design and formal protocol that
151 constrain variation in the data-collection process and allow control for potential sources of bias,
152 such as uneven sampling or species misidentification (Kelling et al., 2019). Also, regarding the
153 issue on detectability that can be inherent to raw count data, previous studies highlighted that raw
154 values are suitable for computing community indices (Devictor & Robert, 2009) and the lack of a
155 distance sampling approach can be compensated by increasing the number of sub-replicates per
156 replicate (as is the case for the FBBS, with 10 point counts per square) (Archaux, Henry &
157 Gimenez, 2012).

158

159 *2.2. Site selection*

160 First, we merged Special Protection Areas (SPAs; Fig. A1) and Special Areas of Conservation
161 (SACs; Fig. A2) networks to get the total cover of N2000 over France (see Appendix A2 for
162 details), and we then calculated the percentage of N2000 area of each FBBS plot. We then defined
163 as N2000 plots those with more than 50% of their surface area overlapping with N2000 areas, and
164 monitored at least twice between 2002 and 2016 ($n = 246$ plots; Fig. 1). As the control group, we
165 further selected neighbouring FBBS plots located in the vicinity of the 246 N2000 plots but outside
166 N2000 areas. To do so, we retained all FBBS plots that fell within a fixed 15 km radius of each
167 N2000 plot and for which less than 50% of the plot's surface area was overlapping with N2000 sites
168 ($n = 417$). For all FBBS plots retained (663 total), we also determined the closest N2000 plot, to be
169 included in further analyses to account for the non-independent spatial structure of selected sites.

170 To specifically compare the efficiency of SPAs and SACs, we applied the same procedure
171 as above, but to each Directive separately, to select SPA and SAC plots (those with more than 50%
172 of their surface area overlapping with SPAs, $n = 195$; respectively SACs, $n = 167$), the
173 neighbouring FBBS plots outside SPAs (SACs) as controls, and the closest SPA (SAC) plots.

174 As other protection measures might influence bird abundances (Devictor et al., 2007;
175 Pellissier et al., 2013), we accounted for other types of protected areas (PAs). Those were classified
176 into two groups according to their protection level: PAs with strong protection status (e.g. National
177 Nature Reserves, National Parks), and PAs with lower protection status (e.g. Regional Nature
178 Parks) (see Appendix A2). Protected areas were merged to get the total cover of each group over
179 France, then we calculated the percentage of PAs with respectively low- and high-level of
180 protection within each FBBS plot.

181 Finally, we determined habitat type within the FBBS plot using Corine Land Cover 2012
182 (Version 18.5.1). We considered as the main habitat one of the five following habitat classes:
183 “farmland”, “woodland”, “urban”, “wetland” or “open water”, when it covered more than 50% of
184 the plot. Plots were defined as “other habitat” when another habitat type covered more than 50% of
185 the plot. Plots with the most abundant habitat covering less than 50% were defined as “mixed
186 habitat”.

187 All GIS analyses were performed using R packages *maptools*, *rgeos*, *raster* and *sp*, in
188 R.3.4.2 (R Core Team, 2017).

189

190 2.3. Community metrics

191 We computed, for each year and each FBBS square, two community indices: the Community
192 Specialization Index (CSI) and the Community Trophic Index (CTrI). The CSI measures the
193 average degree of habitat specialization of a local bird community, defined as the mean of the
194 species specialization index SSI of the censused species weighted by the abundances (Julliard et al.,
195 2006) . The CSI allows for discrimination between generalist and specialist communities. The CTrI
196 measures the average trophic level of a local bird community (Princé et al., 2013). To compute this
197 index, we estimated the proportion of plant, invertebrate and vertebrate items in each bird species’
198 diet (Jiguet et al., 2012). The species trophic index STI was defined as the weighted mean of the
199 diet item proportion values using weight values of 1, 2 and 3 for plant, invertebrate and vertebrate
200 items, respectively. The STI is further exponential-transformed to better contrast communities with
201 or without individuals of the higher trophic levels.

202

203 2.4. Statistical analysis

204 To investigate the effect of N2000 (SPAs+SACs,) on the temporal trends of bird populations, we
205 tested for differences between sites, as defined above, inside or outside the N2000 network for
206 different species groups: the overall common bird population (n = 162 species), habitat guilds
207 (farmland, woodland and generalist), and species listed in the Annex I of the Birds Directive (n =
208 26 species). Habitat guilds consist of 14 generalist species, 24 farmland and 24 woodland specialists
209 that have been classified according to their habitat requirements at the national level (Jiguet et al.
210 2012; and see Table S1 for the list of species for each group). We used, for each species group, a
211 generalized linear mixed model assuming a Poisson error with the N2000 status of the FBBS plot
212 (‘status’ inside or outside N2000), the survey year (‘year’), the habitat type of the FBBS plot
213 (‘habitat’), and the ratio of FBBS plot area covered by low- and high-effect protected areas
214 (respectively, ‘low_protec’ and ‘high_protec’) as covariates. We included the first-order interaction
215 between ‘year’ and ‘N2000’ to assess the effect of N2000 on bird abundances over time. For further

216 interpretation of the results, we considered the level “outside” (i.e. outside the N2000 network) as
217 the contrast group for ‘N2000’ variable. Longitude (X) and latitude (Y) of sites were included to
218 account for potential spatial patterns. To account for different correlation structures in our data and
219 the lack of independence in bird observations, we included ‘year’ as a random term, and we defined
220 a random effect of ‘species’ nested within ‘site’. We also included a random effect of the closest
221 N2000 plot (‘N2000plot’). Given the nature of the response variable (bird count), we tested for
222 potential overdispersion in the model residuals, and fitted the model using a negative binomial error
223 distribution when needed (Appendix A3). We ensured this new model distribution provided a good
224 fit after checking for overdispersion, heterogeneity and residual patterns and non-linearity (Zuur et
225 al., 2009; Zuur and Ieno, 2016).

226 To investigate the long-term effect of N2000 on the bird community structure, we tested for
227 differences in trends of community indices CI (CSI and CTrI) between sites defined as inside or
228 outside the N2000 network. We used a linear mixed model with a Gaussian error distribution. We
229 included the same covariates in the models as for the population abundance models. We also
230 included the interaction between ‘year’ and ‘N2000’ to estimate the effect of N2000 on bird
231 community structure, considering the level “outside” (i.e. outside the N2000 network) as the
232 contrast group for ‘N2000’ variable. We included ‘site’, ‘year’ and ‘N2000plot’ as random effects.

233 Finally, to compare the long-term effect of SPAs and SACs separately, we performed
234 similar modelling as detailed above, at both the population and community levels, on the datasets
235 restricted to SPAs plots and SACs plots, respectively.

236 All models were fitted using the R package *glmmTMB* (Magnusson et al., 2017). Continuous
237 covariates were standardized in order to make all coefficients comparable. Before performing our
238 models, we examined the correlations among explanatory variables used pairwise scatter-plots
239 comparing covariates to detect obvious correlation (Fig. A3). We also performed the variance
240 inflation factor (VIF) analysis to assess collinearity among covariates. All VIF values were well
241 below the threshold of three (Table A2), suggesting low collinearity (Zuur et al., 2009). We
242 inspected spatial correlograms based on the model residuals and did not detect any sign of spatial
243 autocorrelation (for supplementary material, see Appendix 3 and Tables A2-A5).

244

245

246 **3. Results**

247 **3.1. Effects of the N2000 network on common bird populations**

248 We found a significant effect of the whole N2000 network (SPAs+SACs) on the overall common
249 bird population trends (Table 1). Our results highlighted a significant decrease over time of the
250 overall abundance of the 162 species, and this temporal trend was significantly less negative inside

251 than outside N2000 (Table 1; Fig. 2A). When looking specifically at SPAs and SACs separately, we
252 found similar long-term effects of both Directives on the common bird population trends, with
253 SPAs having the strongest positive effect of the three levels examined (i.e. SPA, SIC and Natura
254 2000 sites; Table 1; Fig. 2). Also, we found the overall bird population abundance to be
255 significantly higher inside within SPAs than outside (Table 1).

256 The long-term positive effect of N2000 was stronger on farmland specialist trends, and even
257 stronger when considering SACs only. Indeed the significant decline of farmland specialists over
258 time was significantly lower inside than outside N2000 plots (Table 1; Fig. 3A), and SAC plots
259 (Table 1; Fig. 3B). We did not find any significant effect of SPAs on the long-term trends of
260 farmland bird specialists (Table 1; Fig. A5), i.e. farmland bird populations were declining both
261 inside and outside SPAs.

262 We found no significant effect of N2000 on the temporal trends of both woodland
263 specialists and generalists (Table 1). Though generalists were found less abundant inside than
264 outside N2000, they showed stable trends both inside and outside N2000 similarly to the woodland
265 specialists (Table 1; Fig. A4). We did not find any significant effect of SPAs or SACs on the
266 abundance and the temporal trends of woodland specialists and generalists (Table 1; Fig. A5 and
267 A6).

268 Finally, our results showed that, among the 162 species considered in the study, the 26
269 common species listed in the Annex I of the Birds Directive were significantly more abundant
270 inside than outside N2000, but temporal trends remain stable both inside and outside N2000 (Table
271 1; Fig. A4). Similar results were found when considering each Directive separately (Table 1; Fig.
272 A5 and A6).

273 274 275 **3.2. Effects of the N2000 network on common bird communities**

276 The analysis of the effect of N2000 on the community indices highlighted a significant difference in
277 CSI and CTrI inside vs. outside the whole N2000 network (SPAs+SACs), with both CSI and CTrI
278 being higher inside N2000 (Table 1). This suggests that bird communities in plots inside the N2000
279 network were more specialised and with a higher trophic level than in plots outside N2000. The CSI
280 exhibited a significant negative temporal trend, indicating an increase of generalist species at the
281 expense of specialist species, but with no significant difference between FBBS plots inside and
282 outside N2000 (Table 1; Fig. A7). The CTrI showed stable trends both outside and inside N2000,
283 and no significant difference in temporal trends between plots inside and outside N2000 (Table 1;
284 Fig. A8).

285 The community analyses at the level of each directive (SPA and SAC) did not reveal any
286 obvious difference with the analyses performed at the level of Natura 2000 sites (Table 1; Fig. A7
287 and A8).

288

289

290 **4. Discussion**

291

292 Long-term studies are crucial for any conservation effort (Magurran et al. 2010). They enable
293 formulation of conservation priorities and offer opportunities for an assessment of the
294 effectiveness of conservation policies (Donald et al. 2007). In this study, we used bird data from
295 a long-term volunteer-based monitoring program to investigate the conservation benefits of the
296 Natura 2000 network for non-targeted biodiversity.

297 This paper provides evidence that common bird species - which were not directly targeted
298 by the European Birds and Habitats Directives - may have benefited from the protection or
299 management measures of the N2000 network, but are still in decline. Indeed, we found similar
300 results to previous studies showing a “designation effect” of N2000 on French common birds
301 (Pellissier et al., 2013), with farmland specialists being particularly more abundant, and
302 communities being more specialised and with longer trophic network, within rather than outside
303 N2000 areas. The model captured the well-known significant negative trend of farmland birds
304 (Gregory et al., 2019; OECD, 2019). Our study is also consistent with previous findings pointing
305 out a significant decline of common bird populations over time (Inger et al., 2015), though this
306 decline is less steep within the N2000 network than outside, especially for farmland specialists. In
307 comparison to farmland birds, woodland specialist birds exhibited stable population trends -
308 consistent with recent findings (Gregory et al., 2019) - and these trends did not differ within and
309 outside N2000, similarly to what was found by Pellissier et al. (2013).

310 The significant long-term effects of N2000 on bird population trends we found, especially
311 on farmland birds, stand out from previous studies. This could be explained by the time period and
312 the protected areas considered. Pellissier et al. (2013) considered French bird population trends over
313 a 10-year period (2001-2010), but did not detect any long-term effect except on generalist species.
314 Here, we considered census data over the same period with an additional 5 years of survey, which
315 may have been enough to capture the lag (> 10 years) that is often noted between statutory
316 protection measures and a detectable population-level response (Donald et al., 2007; Male and
317 Bean, 2005; Sanderson et al., 2016; Vorisek et al., 2008). Some environmental trends become
318 apparent only after 10, 15, or 20 years of data collection (Lindenmayer et al., 2018). Thus, in
319 general, the longer a scientifically robust monitoring program has been running and more

320 comparable data points have been collected, the greater the value of these data (Cunningham and
321 Lindenmayer, 2017; Lindenmayer et al., 2018). In addition, by the time of our study, almost all the
322 designated N2000 sites had endorsed management plans (91% in 2016; *unpublished data*), while it
323 was only 50% of the network in Pellissier et al. (2013). It might be argued that we selected sites
324 based on their designation year, which is not always linked to the year of implementation of the
325 management plan. We assume that we may have overestimated the number of Natura sites under
326 management over the entire period. Thus, the results highlighting an effect of Natura are “*a*
327 *minima*” results, meaning that this effect may have been stronger if our analysis had been limited to
328 the sites present from 2001 (thus likely to have been managed over a longer period). Among the
329 few other studies assessing the long-term effect of Natura 2000 on population trends (Gamero et al.,
330 2017; Santana et al., 2014), they focused on SPAs (i.e. sites under the Birds Directive) and found
331 effects of N2000 mostly for Annex I species. In our study, the analysis of the whole network, i.e.
332 both SPAs and SACs, reveals that the Natura 2000 effect on the overall bird population is as much
333 due to SPAs as to SACs. However, when looking at the Habitats and the Birds Directives
334 separately, it seems to rather be SACs (i.e. sites under the Habitats Directive) which contribute to
335 the less steep decline in farmland species within Natura 2000 sites. The SACs contain few
336 agricultural environments such as annual field crops (Rouveyrol, 2016). Indeed, most SACs within
337 agricultural environments concern meadows and hedgerows (environments that are designated for
338 specific habitats or species habitat conservation). Farmland birds must decline less in these
339 environments (meadows and hedgerow areas) which are maintained in the SACs. On the contrary,
340 and in line with the conclusions from Gamero et al. (2017), SPAs have no effect on the national
341 decline of farmland species and may contribute to the protection of mainly target species. In France,
342 measures to support Natura 2000 sites within agricultural environments rely on agri-
343 environmental schemes (AES). Many of the French AES are related to extensive grazing (Princé &
344 Jiguet, 2013) intended to maintain grassland and extensive livestock rearing, both for social
345 (maintenance of agriculture in mountain areas) and environmental (biodiversity, water quality)
346 reasons. The positive but limited effect of N2000 network, and SACs more particularly, on the
347 declining farmland bird populations is in line with previous studies highlighting that French AES
348 are located at suitable locations to promote biodiversity but they might not be efficient enough or
349 not sufficiently spatially implemented to reverse negative population trends (Princé et al., 2012;
350 Princé & Jiguet, 2013).

351 We did not detect significant positive trends for the species of concern listed in the Birds
352 Directive (Annex I) within N2000 areas. We note, however, that our results do not show any
353 significant trend in abundance overall for these specific populations in Natura 2000 sites, meaning
354 that these populations may have remained stable. Various hypotheses can be raised to explain this

355 lack of significant trend on Annex I species. First, we considered only 21 % of the Annex I species
356 present in France, and as they are the most common, it is not surprising that they may not be
357 priority species for site managers. As they are the most abundant of the Annex I species, there is no
358 reason to expect an additional growth, especially within the N2000 sites where we have shown they
359 are more abundant. Besides, there is a strong heterogeneity in population trends (over the period
360 2001-2016) for these targeted species. For instance, based on population trends from Jiguet (2016),
361 increase of abundance of threatened flagship species such as the Red Kite (*Milvus milvus*) (+ 81%),
362 the Black Kite (*Milvus migrans*) (+48%), or the Little Bustard (*Tetrax tetrax*) (+54%), may have
363 dampened the steep decline of other species like Red-backed Shrike (*Lanius collurio*) (-6%, and -
364 24% over the past ten years), Ortolan Bunting (*Emberiza hortulana*) (-57%), Woodlark (*Lullula*
365 *arborea*) (-19%, and -26% over the past ten years) - though those songbirds do not benefit from
366 dedicated conservation plans. More detailed studies monitoring breeding populations for some of
367 these species have demonstrated overall positive trends, and strong positive effects of N2000
368 (Bretagnolle et al., 2011; Santana et al., 2014). Finally, we note that Annex I species in our dataset
369 (n = 26) are not the most abundant over all studied species (n = 165), as these species represent ca.
370 10.5% of the total observations and 2.5% of the total abundance. In comparison, farmland
371 specialists represent ca. 16% of the total observations and 10% of the total abundance, while
372 woodland specialists and generalists represent respectively ca. 18% and 15 % of the total
373 observations, and 14% and 36% of the total abundance within our dataset. As such the power to
374 detect trends from BBS data for Annex I species may be rather low compared to other studied
375 common bird species.

376 The N2000 areas did not show significant long-term protection or management effect on
377 bird communities, and more especially on the negative trend of the community specialization index.
378 Although bird communities harboured more specialist species and with more top predators within
379 N2000 protected areas (which is consistent with previous findings; see Devictor et al., 2008;
380 Pellissier et al., 2013), their designation has obviously not prevented a loss of species over time.
381 And more importantly, the protection network was not able to stop the ongoing functional biotic
382 homogenization. Biotic homogenization refers to the process where few abundant and generalist
383 species are usually replacing a larger number of rare and specialist species (Devictor, Julliard, &
384 Jiguet, 2008; McKinney & Lockwood, 1999). Measures such as High Nature Value farming or
385 agro-environmental schemes have already been shown to be efficient in preventing biotic
386 homogenisation (Doxa et al., 2010, 2012). N2000 farmlands, in particular, exhibit features close to
387 high nature value farmland (high proportion of semi-natural vegetation, low-intensity mosaic
388 farming; Paracchini et al., 2008). The lack of findings may reflect that N2000 network is not

389 sufficient as it is to deliver large benefits at the community level, and could only partially fulfil the
390 European Union's request to protect wild bird species.

391 Overall our study shows that N2000 seems to attenuate the decline of common avifauna,
392 especially for farmland birds, but not to reverse it. Most Natura 2000 sites require active
393 management to maintain their conservation value (Hochkirch et al., 2013b; Ostermann, 1998;
394 WWF, 2017), especially in agricultural areas where the challenge is to provide both economic
395 incentives (through agri-environmental schemes, rural development instruments and other measures
396 including Natura 2000 payments) and advice to landholders for a continuation of wildlife friendly
397 farming practices (Dayer et al., 2018; Hochkirch et al., 2013b; Kati et al., 2015). In this study, we
398 can draw a parallel between our results and the division of the financial resources to the different
399 habitat types within the N2000 French policy. For the 2007-2013 period, Allag-Dhuisme et al.
400 (2016) showed that 764 in 1056 million euros have been given to the sole agri-environmental
401 schemes (AES). By comparison, forest N2000 measures represented only 8 millions, although
402 woodland habitat represents a higher proportion of N2000 sites than farmland (respectively, 49%
403 and 36% considering our whole study period). Over the period 2007-2020, AES accounted for 91%
404 of the value of Natura 2000 contracts, and most of the remaining 9% was also devoted, in other
405 forms, to agro-pastoral environments (unpublished data). As such, agri-environmental measures
406 have always been the main financial source for management in N2000. Management measures are
407 not the only existing tools to achieve N2000 conservation goals, however one may easily link this
408 discrepancy to the results we obtained concerning woodland and farmland species. Pringle et al.
409 (2017) argued that establishment is not enough, and that investments in the PAs after their
410 establishment are key to biodiversity conservation and halting ongoing loss. Also, in line with the
411 "Better, Bigger, More and Joined" mantra (Lawton et al. 2010; Isaac et al. 2018), establishing new
412 sites and expanding the existing PAs while enhancing connectivity among protected sites and
413 improving management plans, are other aspects that can help improve N2000 effectiveness (i.e. to
414 limit biodiversity decline at a larger scale, and reverse the ongoing trends).

415 From our knowledge, this is the first study highlighting significant long-term effects of
416 N2000, at a national scale, on the population trend of non-targeted avian biodiversity. Although
417 protected areas are currently identified as a key strategy for the success of specific conservation
418 goals (Godet and Devictor, 2018), we can here emphasize that N2000 network as a whole should be
419 seen as an important element to protect not only species of community interest but a wider spectrum
420 of species within the common biodiversity, at national scale. This seems particularly important in
421 the current context of continuous, strong decline of biodiversity (IPBES 2019), and when most of
422 the birds currently considered as non-threatened, will probably be threatened in the near future.
423 Also, as rightly pointed out by Hermoso et al. (2019), halting loss of biodiversity in the EU likely

424 requires moving beyond the fixed lists that currently guide conservation efforts to better cover
425 threatened species (Hermoso et al., 2017; Hochkirch et al., 2013b). We acknowledge that the impact
426 of conservation actions, and of the entire network, should be evaluated on a regular basis with tools
427 such as bird indicators and following the BBMJ strategies (Isaac et al. 2018), to assess the success
428 or failure in conserving bird populations and, consequently, in conserving ecosystem functions and
429 biodiversity as a whole. Finally, we stress that management data are needed to have a better sense
430 of the relationship between management inputs and biodiversity outcomes in N2000 networks, and
431 more generally in protected areas. A recent global-scale study from Geldman et al. (2018)
432 highlighted the lack of suitable data for rigorous testing of the role of protected areas management
433 in maintaining species populations across multiple sites, France and EU being prime examples.

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445 **Data**

446 Data is available upon request via a dedicated website at [www.vigienature.fr/fr/acces-donnees-](http://www.vigienature.fr/fr/acces-donnees-3611)
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688

689 **Figure captions**

690

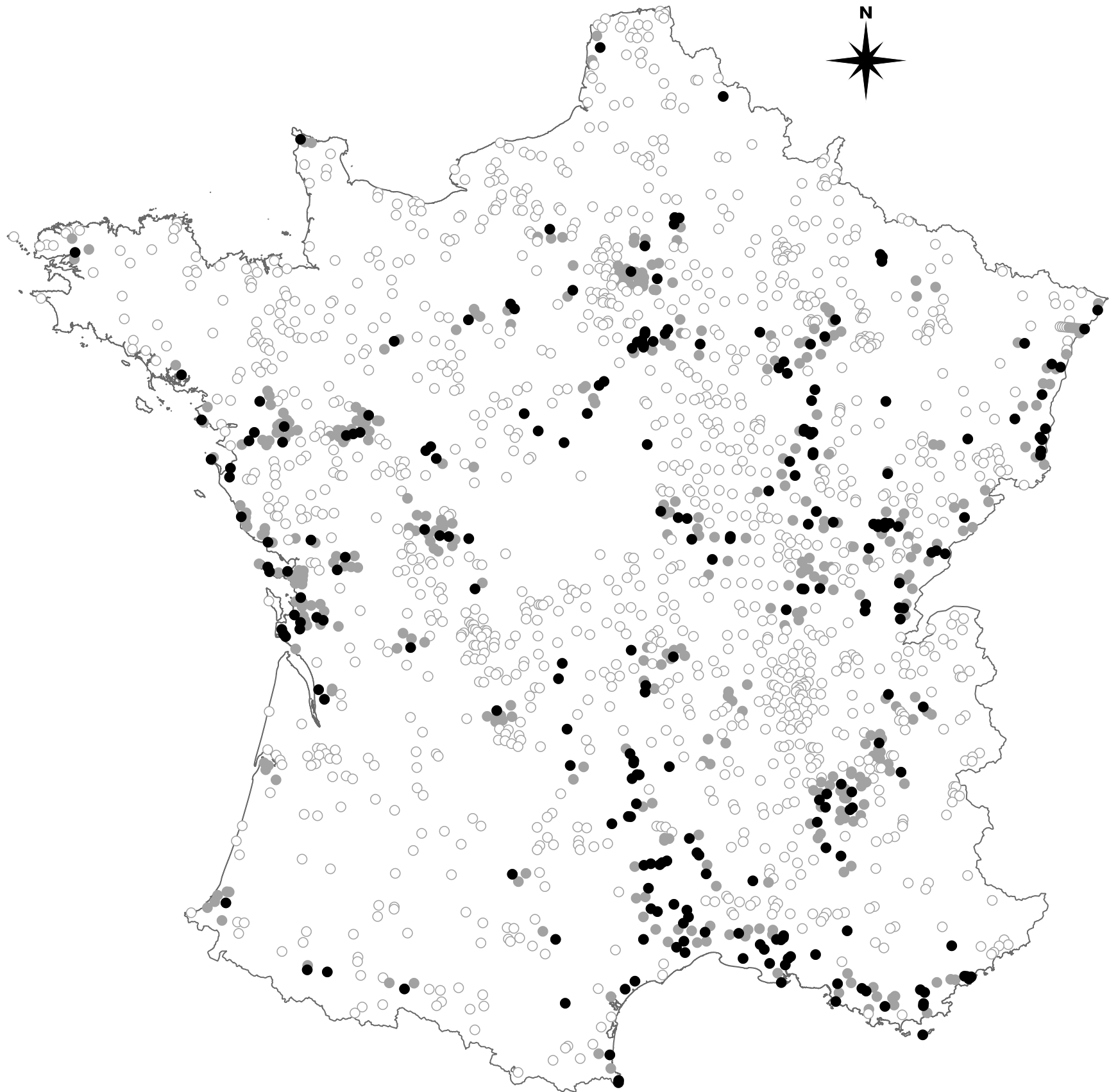
691 **Figure 1.** Spatial distribution of the French Breeding Survey plots. Each dot represents a 2 x 2-km
692 plot monitored at least twice between 2002 and 2016. Black dots indicate plots considered as
693 “inside Natura 2000”, i.e. with a proportion of N2000 coverage that exceeds 50% of the plot (n =
694 246). Grey dots indicate plots considered as “outside Natura 2000” but within 15 km of a N2000
695 plot (n = 417). Grey-circled white dots correspond to the rest of the FBBS plots.

696

697 **Figure 2.** Temporal trends in abundance of the overall common bird populations within (in blue)
698 and outside (in red) (A) the whole Natura 2000 network (B) Special Protection Areas (under Bird
699 Directive), and (C) Special Areas of Conservation (under Habitat Directive). Lines represent the
700 model predictions based on the corresponding estimates of the interaction between ‘*year*’ and
701 ‘*N2000*’ of the GLMMs presented in Table 1, and bands represent the 95% confidence intervals.

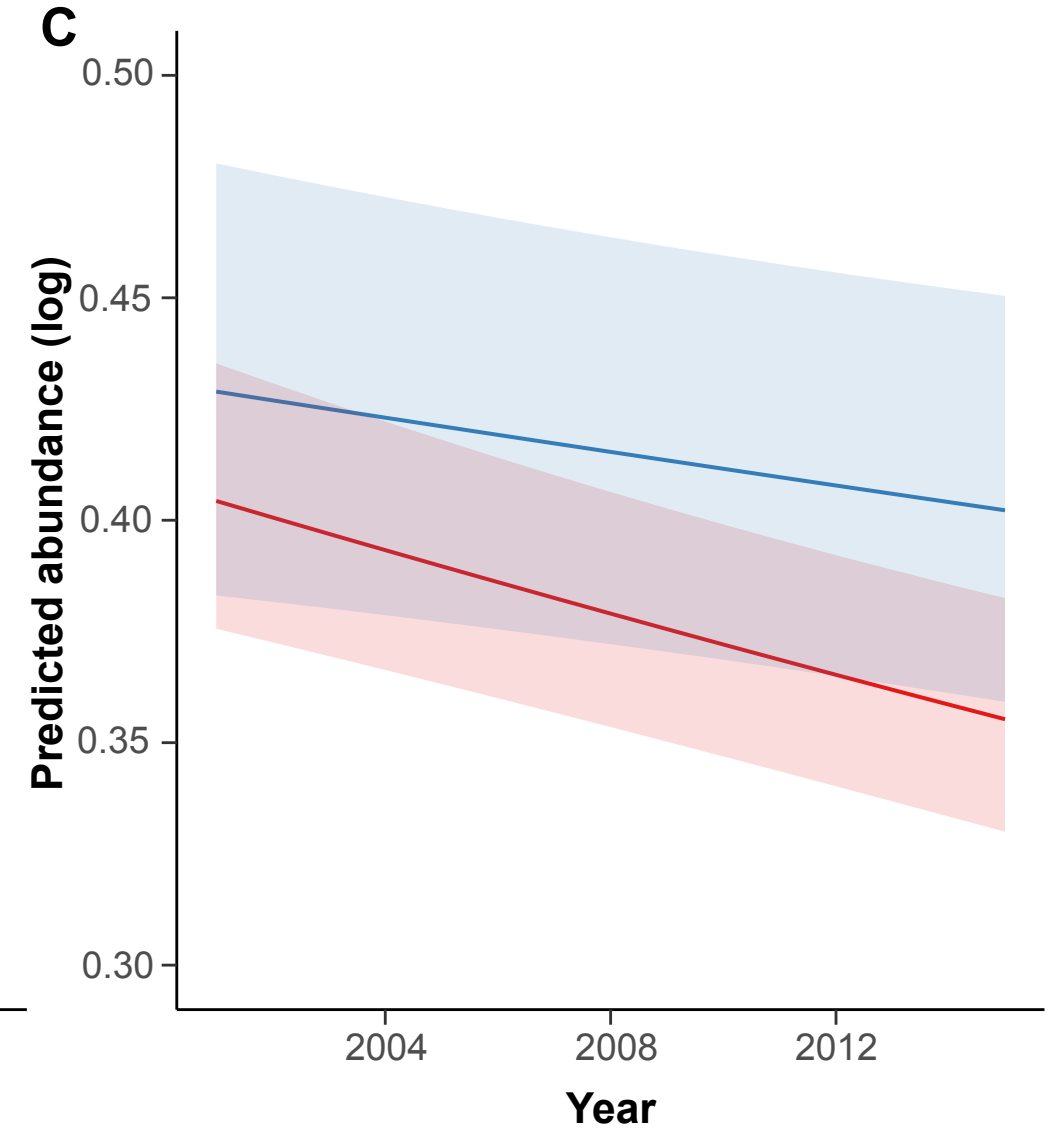
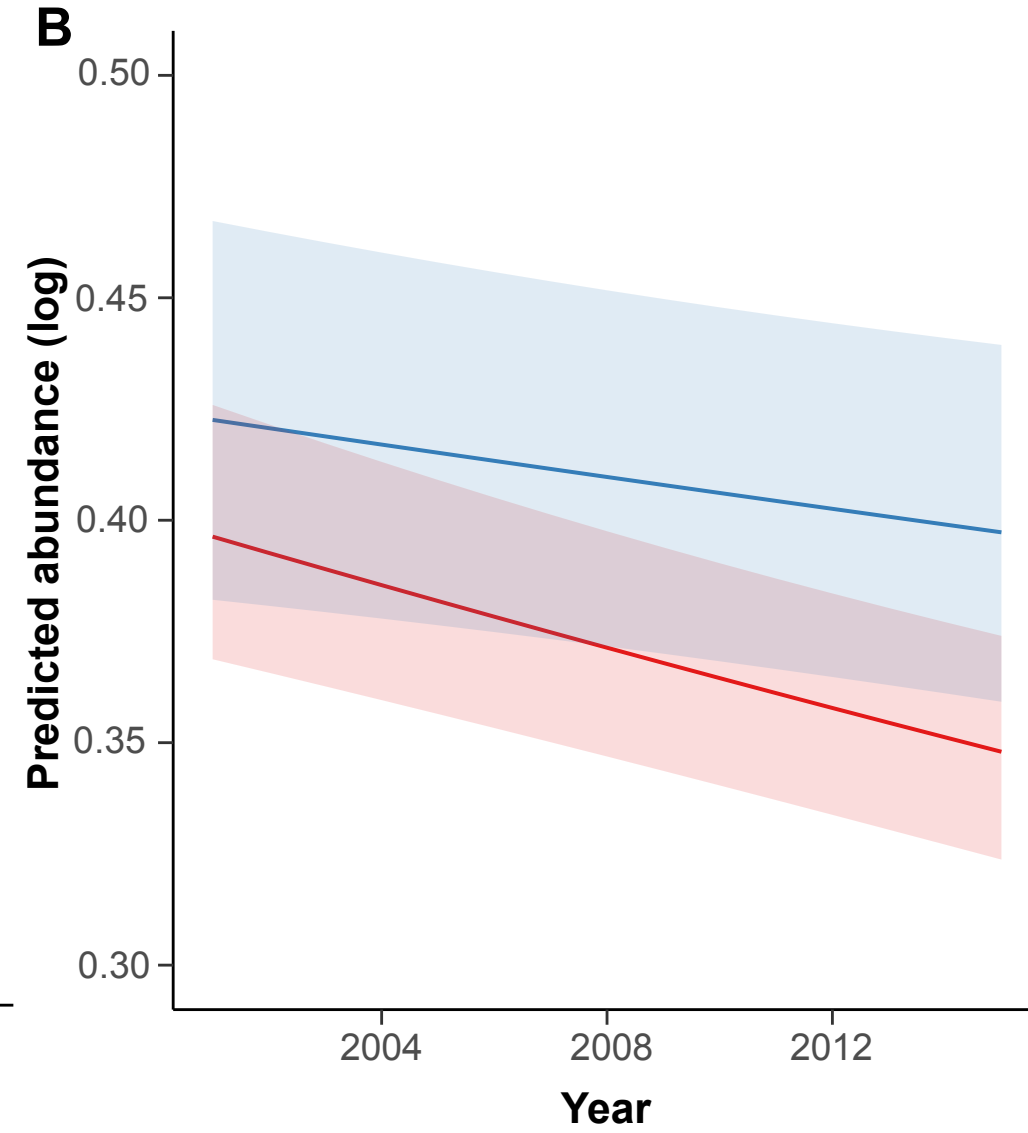
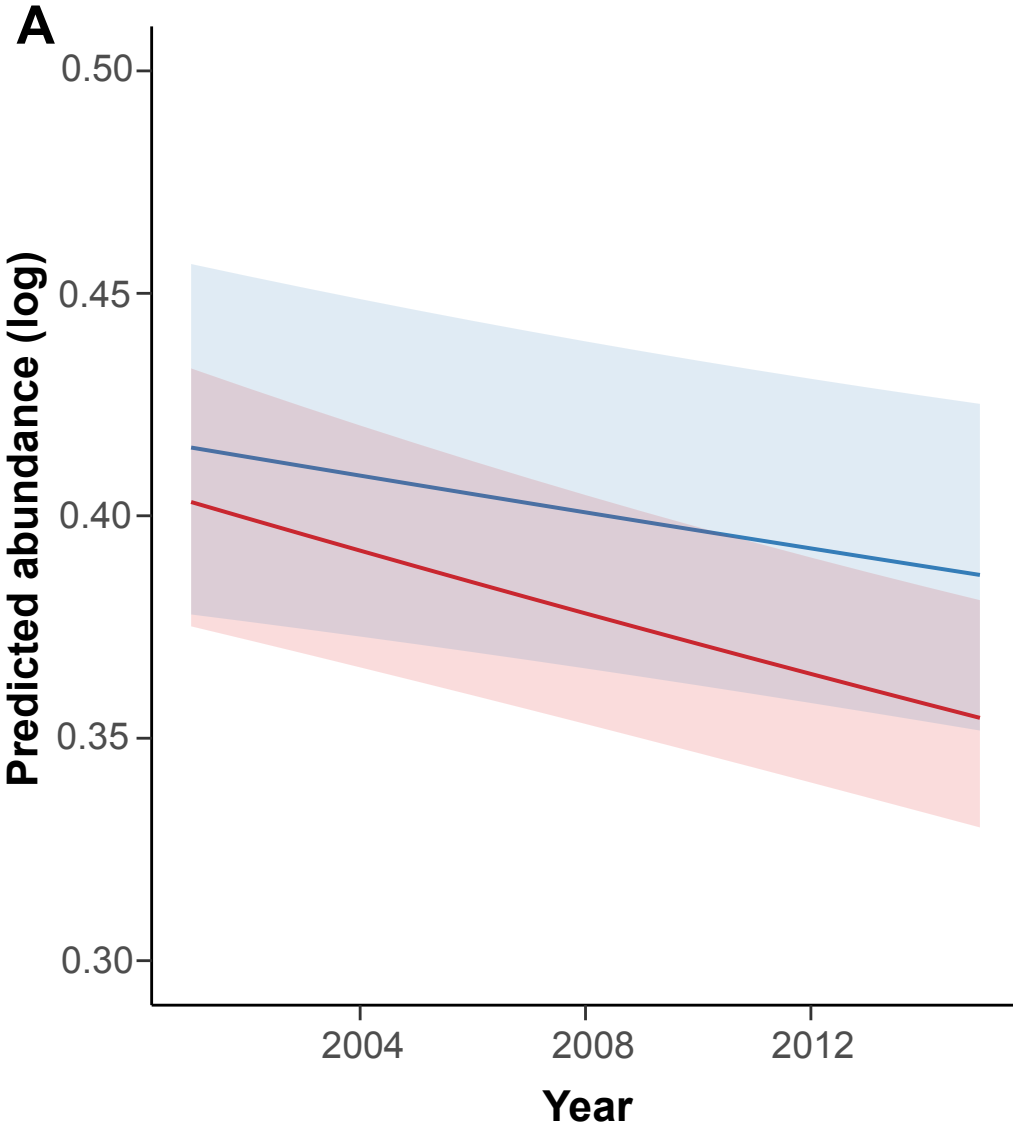
702

703 **Figure 3.** Temporal trends in abundance of the farmland bird populations within (in blue) and
704 outside (in red) (A) the whole Natura 2000 network and (B) Special Areas of Conservation (under
705 Habitat Directive). Lines represent the model predictions based on the corresponding estimates of
706 the interaction between ‘*year*’ and ‘*N2000*’ of the GLMMs presented in Table 1, and bands
707 represent the 95% confidence intervals.



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300 km



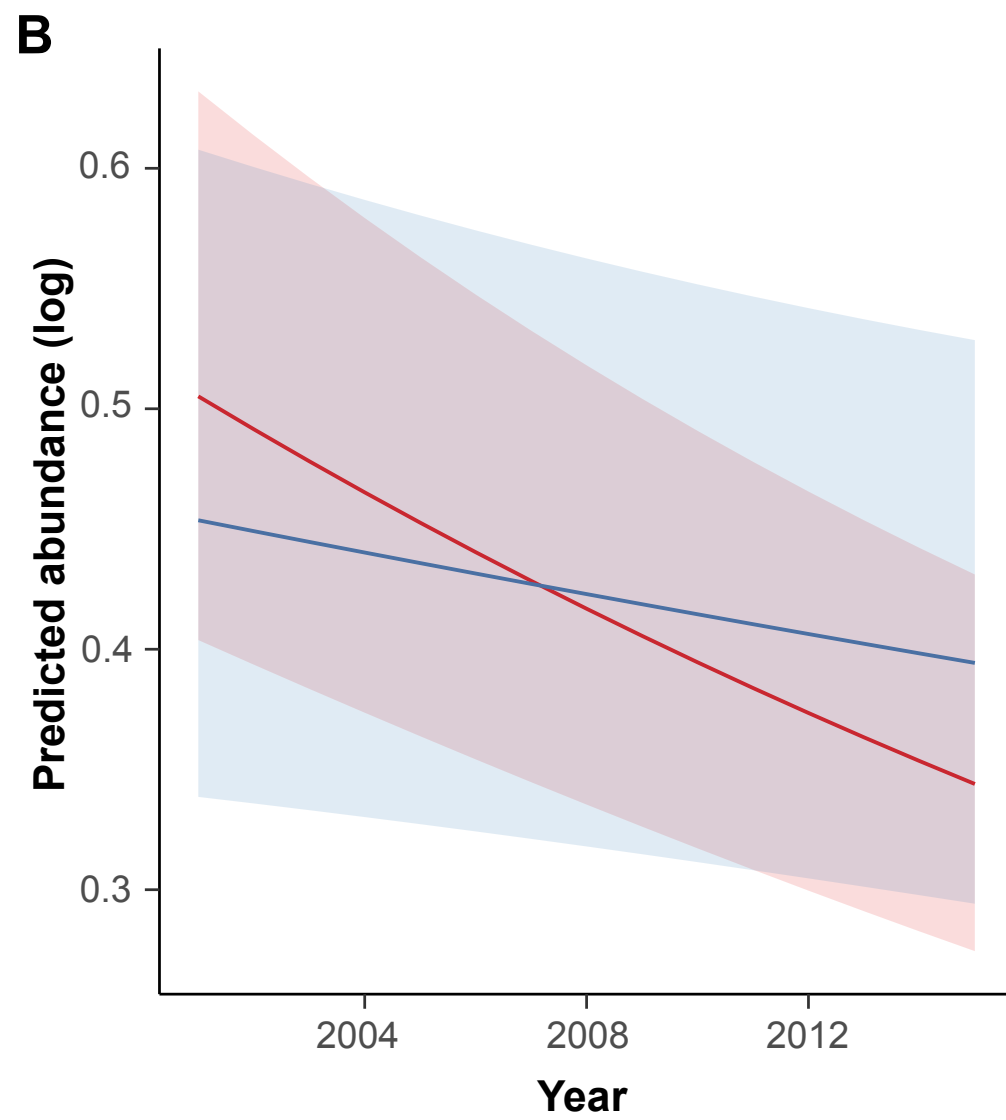
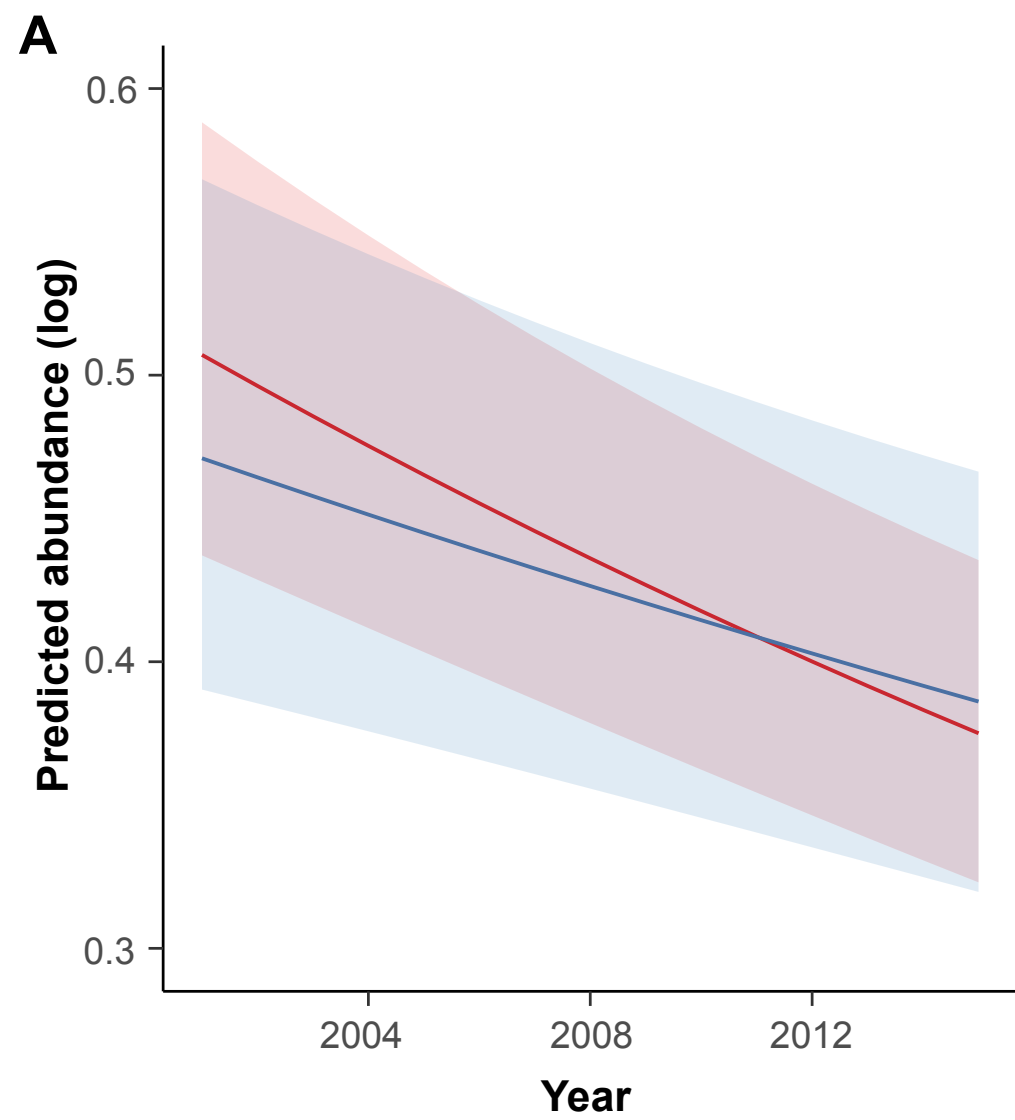


Table 1. Partial regression coefficients from the Generalized Linear Mixed Models investigating the effects of the whole Natura 2000 network (SPAs and SACs together), and of SPAs and SACs separately, on the temporal trends of bird abundances and community metrics. P-value level of significance associated are ‘***’ P < 0.001; ‘**’ P < 0.01; ‘*’ P < 0.05.

Bird metric	N2000	SPAs	SACs
<i>Abundance of all 162 species</i>			
Status(inside) [†]	0.025 ± 0.047	0.225 ± 0.077 **	0.024 ± 0.060
Year	-0.036 ± 0.007 ***	-0.052 ± 0.008 ***	-0.051 ± 0.008 ***
Status(inside) [†] :Year	0.016 ± 0.004 ***	0.028 ± 0.010 **	0.019 ± 0.008 **
<i>Abundance of Farmland specialists</i>			
Status(inside) [†]	-0.025 ± 0.093	0.325 ± 0.208	0.008 ± 0.143
Year	-0.085 ± 0.013 ***	-0.112 ± 0.017 ***	-0.109 ± 0.017 ***
Status(inside) [†] :Year	0.029 ± 0.013 *	0.048 ± 0.033	0.069 ± 0.016 ***
<i>Abundance of Woodland specialists</i>			
Status(inside) [†]	0.017 ± 0.072	-0.011 ± 0.136	0.109 ± 0.093
Year	-0.023 ± 0.014	-0.021 ± 0.017	-0.021 ± 0.017
Status(inside) [†] :Year	-0.004 ± 0.007	-0.006 ± 0.016	-0.011 ± 0.011
<i>Abundance of Generalists</i>			
Status(inside) [†]	-0.107 ± 0.045 *	0.043 ± 0.098	-0.031 ± 0.068
Year	0.012 ± 0.009	-0.000 ± 0.008	-0.000 ± 0.009
Status(inside) [†] :Year	-0.005 ± 0.005	0.007 ± 0.013	0.005 ± 0.009
<i>Abundance of Annex I species</i>			
Status(inside) [†]	0.688 ± 0.077 ***	0.822 ± 0.177 ***	0.711 ± 0.123 ***
Year	0.001 ± 0.015	0.013 ± 0.025	0.015 ± 0.027
Status(inside) [†] :Year	0.016 ± 0.017	-0.066 ± 0.043	-0.072 ± 0.034
<i>Community Specialisation Index</i>			
Status(inside) [†]	0.041 ± 0.013 **	0.059 ± 0.015 ***	0.057 ± 0.017 **
Year	-0.006 ± 0.002 **	-0.006 ± 0.002 **	-0.006 ± 0.002 *
Status(inside) [†] :Year	0.001 ± 0.003	0.002 ± 0.003	0.002 ± 0.003
<i>Community Trophic Index</i>			
Status(inside) [†]	0.743 ± 0.107 ***	0.798 ± 0.117 ***	0.846 ± 0.131 ***
Year	-0.032 ± 0.033	-0.032 ± 0.030	-0.033 ± 0.035
Status(inside) [†] :Year	-0.037 ± 0.034	0.016 ± 0.036	-0.019 ± 0.042

† Contrast group for *Status* variable is outside, i.e. outside N2000 network (SPAs+SACs), or SPAs or SACs.

Note: Abundances of the overall common bird population (n = 162 species), farmland specialists (n = 24) and generalists (n = 14) were modelled using a negative binomial distribution. Abundances of woodland specialists (n = 24) and Annex I species (n = 26) were modelled using a Poisson error distribution. Community metrics were modelled using a Gaussian error distribution. Habitat type of the FBBS plot (*Habitat*), the ratio of FBBS plot area covered by protected areas with low and high level of protection (respectively, *Low_protec* and *High_protec*), longitude (*X*) and latitude (*Y*) of the FBBS plot were included as controlling effects in the regression models (see Supplementary material, Table A3-A5, for detailed results).