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Site-based *vs*. species-based analyses of long-term farmland bird datasets: Implications for conservation policy evaluations

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A B S T R A C T

Conservation of Europe's biodiversity increasingly depends on funds invested within Natura 2000 farmland. Performance of these investments is estimated by the official Farmland Bird Index indicator, that merges species-specific trends for farmland species estimated with the standard TRIM method. We here reanalyze the long-term datasets used to calculate the Spanish Farmland Bird Index by computing abundance and richness of selected bird groups at the point census scale rather than by merging species' trends. We test whether community trends at site scales differed according to agricultural habitat types (annual, perennial, and mosaic croplands) and locations inside or outside Natura 2000 sites, using both the TRIM method and generalized mixed models. Site-based analyses showed a general increase in bird abundance and richness outside the Natura 2000 network, and a general decrease in perennial and mosaic croplands inside it. Increasing trends were due to non-farmland birds occupying farmland, as farmland species showed significant decreasing trends overall, especially inside Natura 2000 sites and for steppic birds. Trends for threatened birds in annual cropland located inside Nature 2000 were positive, but trends for threatened farmland birds were negative overall, especially in mosaic croplands. Results were qualitatively consistent among statistical methods, although quantitative estimates varied widely among methods, habitats, Natura 2000 location, and relevant bird groups. Site-based analyses of long-term databases confirmed overall trends detected by species-based official reports, and complement them by suggesting additional reasons for failures at reverting negative trends in farmland biodiversity. Regionally-targeted conservation measures should be developed and/or extended to improve these results, and their results monitored at the farm scale to complement the low spatial resolution of volunteer-based bird monitoring schemes. Combination of broad–scale citizen science programs with cause-effect, finer-scale studies will help disentangle the causes of the observed patterns to develop better and more efficient recommendations for conservation measures in farmland areas.

1. Introduction

Cultural landscapes resulting from the interplay between natural resources and human uses are essential for biodiversity conservation (Foley et al., 2011; Campos et al., 2013; Mendenhall et al., 2014). Long-term interactions with low-intensity farming practices led to the expansion and development of species-rich communities linked to these cultural landscapes (e.g. Moreno et al., 2016). Nevertheless, these communities are now threatened by rapid land use change, especially agricultural intensification in the most productive areas and abandonment of economically marginal but highly diverse farms (Donald et al., 2006; Plieninger et al., 2014).

Conservation strategies based on active management and exclusion of uses in natural or semi-natural areas has proved to be generally successful for large-sized species threatened by the expansion of human activities (Donald et al., 2007). Effective biodiversity protection in the wider countryside to complement site-based strategies is one of the main objectives of the European Natura 2000 network (Princé et al. 2021 and references therein). This network includes legally protected areas for priority species and habitats, but most of the land included in it remains privately owned and are thus managed for productive uses. Member States must ensure that site management is done in a sustainable

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manner, both ecologically and economically, to guarantee the long-term survival of species, habitat types and extensive land uses that maintain these systems, helping to stop the current loss of biodiversity in Europe (EC, 2013).

Substantial conservation investment has been made to maintain the Natura 2000 network through the LIFE-Nature program and Common Agriculture Policy (CAP) funds. However, evaluation of the performance of these funds (mainly CAP's) to effectively preserve the species protected by this network are still scarce, particularly at the site- and habitat scales (Santana et al., 2014; Concepción, 2021; Gameiro et al., 2020; Portaccio et al., 2021; Princé et al., 2021). So far, the analysis of the trends of the species protected by the Natura 2000 network and the Nature Directives has been based on species-by-species monitoring (e.g. De Victor et al., 2012; Pellissier et al., 2013, 2020; Princé et al., 2021), classifying each species according to the general type of habitat to which they are associated to deduce these trends at the habitat scale (Inger et al., 2015; Brlík et al., 2021). Nevertheless, if the aim is to evaluate whether general conservation policies are effective in preserving global biological diversity maintained by each of the European habitats (Díaz and Concepción, 2016) it would be more accurate to analyze the trends of community parameters (abundance and species richness) directly at this habitat scale (Torre et al., 2015). The reason for this is that species-by-species approaches can lead to misleading interpretations if a high proportion of the species is linked to several habitats, as it is usual for Mediterranean communities (Blondel et al., 2010).

We present here the results of a comprehensive site-based analyses of the recent trends of bird communities occupying agricultural habitats in mainland Spain over the past 20 years. Spain is the second largest European country, also second to France in agricultural land area and CAP funds received (EC, 2019), and probably the most important for the conservation of European farmland birds (Traba and Morales, 2019, and references therein). Species-by-species approaches have usually shown mixed trends, with local or general increases of some formerly highly endangered species (de Juana, 2004) and decreases for others (Palacín and Alonso, 2018; Traba and Morales, 2019). Local studies at the community level usually show positive effects of the most targeted CAP conservation measures (agrienvironmental schemes) on bird abundance and diversity (Kleijn et al., 2006; Concepción and Díaz, 2011, 2019; Concepción et al., 2012; Tarjuelo et al. 2021). Nevertheless, these targeted measures have been scarcely implemented so far, and there is recent evidence that other CAP measures of wider application (cross-compliance and, especially greening payments) have not been effective overall for farmland bird conservation (Concepción et al., 2020). Yearly reports of trends of selected species of common farmland birds integrated in the Farmland Bird Index showed an overall negative trend (23% decrease from 1998 to 2017; SEO/BirdLife, 2020; http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_bio2&lang=en), but no general evaluation of the trends of Spanish bird communities on farmland has been done to date (see Portaccio et al., 2021; Princé et al., 2021 for similar attempts in other EU countries).

Here we investigate diversity trends of the overall bird community in farmland, as well as of the species' groups most closely associated to agricultural habitats (farmland and steppic birds) and of threatened birds (see Concepción and Díaz, 2019; Concepción et al., 2020; Tarjuelo et al. 2021 for similar approaches). We also analyze whether bird diversity trends differ among farmland types (annual, perennial, and mosaic cropland) and inside and outside the Natura 2000 network. Differences between farmland types are expected due to differences in sensitivity of bird species typical of these types to the changes experienced by European agriculture in recent years (Díaz and Concepción, 2016; Concepción et al. 2020, Tarjuelo et al. 2021). For instance, open-land birds typical for annual crops can be negatively affected by the expansion of small afforestations on former arable land, woody edges, or perennial crops (Santos et al., 2006; Reino et al., 2009; Santana et al., 2014; Díaz and Concepción, 2016; Concepción and Díaz, 2011, 2019). Trends are expected to be more positive (or less negative) within the Natura 2000 network (Pellissier et al., 2013, 2020; Santana et al., 2014; Gamero et al., 2017; Portaccio et al., 2021; Princé et al., 2021) due to higher conservation investment inside than outside Natura 2000 (conservation-oriented agrienvironmental schemes cannot be taken outside Natura 2000 sites in Spain, although overall uptake is quite low, in the order of tens of thousands hectares; https://www.mapa.gob.es/es/estadistica/temas/publicaciones/anuario-de-estadistica/default.aspx) or weaker intensification trends (Santana et al., 2014; Princé et al., 2021, and references therein).

Result of these site- and habitat-focused analyses will complement the usual species-focused analyses of long-term datasets to provide additional evaluations of the performance (or lack thereof) of farmland conservation policies, especially if target species depend on habitat types other than farmland. Site-based analyses would also provide performance indicators at finer spatial scales than the country-level official Farmland Bird Index (Díaz et al., 2021; Portaccio et al., 2021; Princé et al., 2021), or suggest additional monitoring schemes if the current ones were too coarse in relation to the surface surveyed. Finally, we test whether the official method to compute species' population trends is also useful for estimating trends of community parameters (abundance and species richness of selected bird groups; Portaccio et al., 2021; Princé et al., 2021).

2. Materials and methods

2.1. Data selection

Trends of bird abundance and species richness in agricultural habitats of mainland Spain were extracted from the SACRE monitoring program maintained by SEO/BirdLife since 1998 (SEO/BirdLife, 2020, and references therein). This program collects data on the abundance of bird species following standardized protocols for the production of national and European-wide indices of their population size change (Brlík et al., 2021). SACRE monitors bird abundances in spring by means of 20 5-min. point census stations per 10 km × 10 km UTM square carried out by skilled volunteers. All birds seen or heard inside and outside a radius of 50 m around the observer are recorded. The 20 stations are distributed in a stratified manner according to the habitat types present in the UTM square (as classified by volunteers following SACRE's templates; www.seo.org/sacre/). Censuses are performed twice a year, at the beginning and at the end of the local breeding season (Brlík et al., 2021). This method renders robust estimates of population trends for bird monitoring schemes (Carrascal and del Moral, 2020) and has also been used to analyse spatial responses of bird communities to agricultural land use change (Concepción et al., 2020).

We selected from the full 1998–2017 database provided by SEO/BirdLife the sampling stations located in agricultural habitats (category E: habitats under evident agricultural management that reach a coverage in the census area higher than the 25%; see SACRE templates at www.seo.org/sacre/). Richness was calculated from the list of species identified in the two visits. Abundance of birds was the sum of the highest counts of each species recorded in both visits. Richness and abundance were computed for a) the entire set of bird species detected; b) for the subset of birds more linked to agricultural habitats; and c) for threatened birds only (included in the critically endangered, endangered and vulnerable IUCN categories in Spain; Díaz et al., 2018), either farmland birds or overall. Subsets of birds more linked to agricultural habitats were either those officially classified as such in Europe (39 species of European common farmland birds; https://ec.europa.eu/eurostat/cache/metadata/en/env_biodiv_esms.htm#unit_measure1618589073301) or those specialist of farmland habitats in Spain (29 species of steppic birds; Suárez et al., 1997; Appendix). Definition of these species' subsets were based on the current conservation policies for farmland birds established by Spanish authorities (see Concepción and Díaz, 2019; Concepción et al., 2020; Tarjuelo et al. 2021, for details).

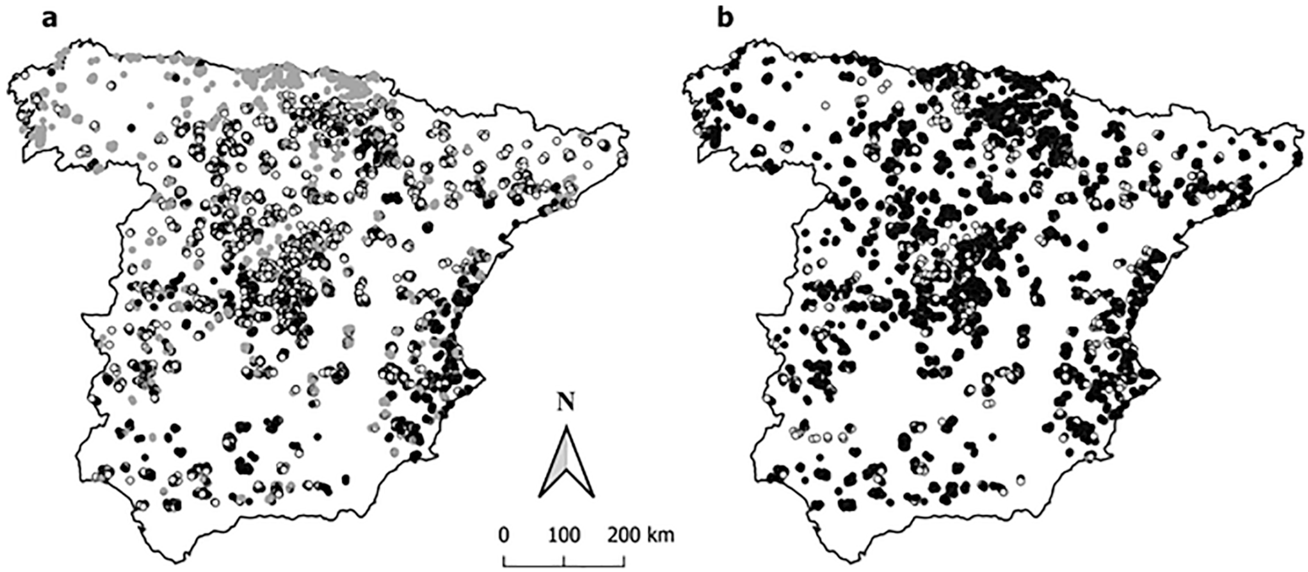

Fig. 1. Spatial distribution of the 9,589 valid point counts of the SACRE program surveyed during the 1998–2017 period and located in agricultural habitats according to a) habitat type (white: annual crops, n = 5,053; black: perennial crops, n = 1,776; grey: mosaic annual-perennial, n = 2,760) and b) Natura 2000 status (open: sites inside, n = 1,568; filled: sites outside, n = 8,021).

Agricultural habitats were classified as annual, perennial or mosaic crops by volunteers each census year according to the SACRE protocol (www.seo.org/wp-content/uploads/2012/04/Excel-h%C3%A1bitats-SEO5.pdf). Annual croplands include habitat codes 31 (rainfeed cereals and legumes), 32 (irrigated crops) and 33 (rice fields); perennial crops include codes 34 (olive groves), 35 (vineyards) and 36 (orchards); and mosaic cropland codes 37 (Mediterranean mixed arable farmland) and 54 (Eurosiberian mixed arable farmland; Appendix). The location of stations inside or outside the Natura 2000 network were obtained by GIS overlapping (ArcGIS; ESRI, 2018) of the station's 50-m buffers with the official map of the network provided by the Ministry of Agriculture, Fisheries, Food and Environment (scale 1: 50,000 and updated to December 2017). The map includes the date of creation of each Natura 2000 site. Census stations included in 10 km × 10 km UTM grids only partially included in protected sites were assigned using their exact geographic locations when available, whereas all stations within the 10 km × 10 km UTM squares falling entirely either inside or outside Natura 2000 sites were assigned accordingly.

2.2. *Statistical analyses*

Temporal trends in the abundance and richness of bird assemblages (all birds, farmland birds, and threatened birds) and the effect of farmland habitat type and Natura 2000 status on trends were analysed by fitting Generalized Linear Mixed Models (GLMMs; Princé et al., 2021). For each assemblage and response variable (species richness or bird abundance) we adjusted a GLMM assuming a Poisson error distribution with the survey year as a covariate and the farmland habitat type (annual, perennial or mosaic cropland) and the Natura 2000 status (inside or outside) as fixed factors. Two-way interactions between year and habitat and between year and Natura 2000 status tested if trends in richness and abundance differed between habitats and according to Natura 2000 status. The three-way interaction tested whether habitat trends differed inside and outside Natura 2000 sites. Point count stations were included as a random term to test trends at the point count level, as well as to account for spatial effects on both counts and trends. Random intercept and random slope were modelled, except in two cases were variance of the slope was close to zero, where only random intercept was included (Magnusson et al., 2017). Year was also included as a random term to account for temporal autocorrelation (see Princé et al., 2021 for a similar approach). Slopes for trends (and their deviation for the null-slope hypotheses) and overall 20-year change in the response variable for each combination of factor levels were computed by running the models with the combinations of the habitat and Natura 2000 factors as levels of a single fixed factor (e.g. 'Annual-Inside', 'Annual-Outside', 'Mosaic-Inside', etc.). The overall trends without considering habitat and Natura 2000 effects were calculated by fitting GLMMs with the year covariate and no fixed factors. We checked residuals for overdispersion, nonlinearity and atypical patterns. When detected, new models using a negative binomial or a zero-inflated negative binomial error distribution were fitted instead. Spatial correlograms based on the model residuals did not show any sign of spatial autocorrelation (Princé et al. 2021). All models were fitted using the package glmmTMB (Magnusson et al., 2017) in R (R Core Team, 2018).

Species-specific trends are routinely computed using the TRIM (Trends and Indices for Monitoring Data) protocol and merged for species dependent of each habitat type to compute the official habitat-type trends (https://ec.europa.eu/eurostat/cache/metadata/en/env_biodiv_esms.htm#unit_measure1618589073301). TRIM uses generalized estimating equations (GEE) for the analysis of repeated measures data at permanent sampling sites, interpolating trends if time series are moderately incomplete. Poisson distribution of errors and logarithmic link functions were used to best suit count data (Bogaart et al., 2018). We computed trends of bird abundance and richness throughout the 1998–2017 for total, agricultural and threatened birds following the TRIM protocol using the R-TRIM software in R (Bogaart et al., 2018). Type of agricultural habitat (annual, perennial or mosaic annual-perennial) and location inside or outside the Natura 2000 network were included as fixed factors.

3. Results

3.1. *The database*

The SACRE database includes ca. three million records of birds detected in 5-min. bird counts made from 1998 to 2017 in Spain. We selected data gathered at 9,589 farmland stations located in 479 10 km × 10 km UTM squares (Fig. 1) after excluding 2,620 stations surveyed only once, 588 whose habitat changed and 83 whose Natura 2000 status changed during the study period (15 of these also changed habitat). 698 stations with no precise geographic coordinates or located outside

Response variable		GLMM: all species detected	GLMM: excluding species most likely detected in other habitats	TRIM: all species detected	TRIM: excluding species most likely detected in other habitats
Species richness	Overall trend	**13.80**	**13.31**	**9.60**	**8.60**
	Annual-Inside	2.61	1.20	**6.60**	**6.80**
	Mosaic-Inside	-6.60	-7.22	15.60	15.40
	Perennial-Inside	-8.89	-8.68	1.40	0.60
	Annual-Outside	**11.74**	**11.20**	**9.20**	**9.40**
	Mosaic-Outside	**9.01**	**8.29**	**12.20**	**11.00**
	Perennial-Outside	**13.51**	**12.99**	**15.40**	**14.20**
Abundance	Overall trend	**8.17**	**8.99**	7.40	5.60
	Annual-Inside	6.54	7.73	4.80	9.60
	Mosaic-Inside	-12.37	-13.71	**44.60**	**43.20**
	Perennial-Inside	**-24.03**	**-20.67**	**-18.00**	0.00
	Annual-Outside	**12.67**	**13.41**	**11.20**	**9.60**
	Mosaic-Outside	5.80	7.92	1.20	0.00
	Perennial-Outside	8.84	5.77	**18.00**	**9.20**
		EU	Steppic	EU	Steppic
Farmland birds' richness	Overall trend	**-10.28**	**-15.59**	-10.00	**-28.00**
	Annual-Inside	**-8.25**	**-11.62**	**-14.00**	**-22.00**
	Mosaic-Inside	**-22.84**	-17.76	-10.00	-32.00
	Perennial-Inside	**-18.76**	-10.28	**-22.00**	**-24.00**
	Annual-Outside	-3.98	**-7.70**	**-6.00**	**-14.00**
	Mosaic-Outside	-5.03	4.99	-2.00	**-28.00**
	Perennial-Outside	**-7.77**	**-14.95**	-4.00	**-18.00**
Farmland birds' abundance	Overall trend	**-11.83**	**-31.70**	-6.00	**-20.00**
	Annual-Inside	-3.00	-11.33	**-18.00**	**-24.00**
	Mosaic-Inside	**-24.28**	**-30.94**	34.00	-22.00
	Perennial-Inside	**-27.48**	-19.96	-22.00	-10.00
	Annual-Outside	3.52	**-13.83**	0.00	**-20.00**
	Mosaic-Outside	-4.80	**-18.96**	-12.00	**-26.00**
	Perennial-Outside	-9.54	**-27.03**	-2.00	**-14.00**
		all species detected	farmland birds only	all species detected	farmland birds only
Threatened birds' richness	Overall trend	-1.38	-8.90	1.60	-26.00
	Annual-Inside	**45.20**	-1.24	**36.60**	-18.00
	Mosaic-Inside	40.39	-5.31	-28.00	-46.00
	Perennial-Inside	32.69	0.97	14.80	-16.00
	Annual-Outside	9.15	-0.20	5.00	6.00
	Mosaic-Outside	13.48	0.01	-12.00	-10.00
	Perennial-Outside	-7.41	-10.13	2.00	-6.00
Threatened birds' abundance	Overall trend	-5.50	**-20.06**	**-30.00**	-22.00
	Annual-Inside	**77.32**	-5.09	**81.80**	0.00
	Mosaic-Inside	32.05	**-60.39**	-60.00	**-94.00**
	Perennial-Inside	33.56	-12.24	-20.00	-20.00
	Annual-Outside	11.68	-5.39	**29.20**	12.80
	Mosaic-Outside	-10.06	-17.52	**-36.00**	-12.00
	Perennial-Outside	-14.92	**-19.90**	6.80	-10.00

Fig. 2. Heat map showing the percent change in bird species richness and abundance from 1998 to 2017 in mainland Spain according to agricultural habitat (annual, mosaic or perennial crops), location inside or outside Natura 2000 sites, bird species groups (all species detected, or excluding species most likely using habitats other than agricultural, for all birds, farmland birds and threatened birds), and statistical method to analyse trends (GLMMs with sampling stations as the random factor, or TRIM models). Boldface indicate p > 0.05. Green: positive trends. Red: negative trends. See text for definitions and Suppl. Tables 1-3 for the statistical details of model fitting results.

Table 1
Results of GLMM models testing for effects of farmland habitat and the Natura 2000 network on trend of bird community parameters. The best-fitting distribution of residuals corresponded to a Poisson distribution for species richness and a Negative Binomial for bird abundance. Boldface indicates p < 0.05. Further details can be found un Suppl. Table 1.

		all species, excluding contacts from non-agricultural habitats			EU-farmland birds			Steppic birds			Threatened birds			Threatened EU farmland birds		
Response	**Effect**	χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p	χ^2	df	p
Species richness	Year	**10.58**	**1**	**0.001**	5.78	1	0.016	**7.84**	**1**	**0.005**	**5.73**	**1**	**0.017**	0.20	1	0.657
	Farmland habitat	**423.82**	**2**	**0.000**	**461.64**	**2**	**0.000**	**2138.70**	**2**	**0.000**	**209.15**	**2**	**0.000**	**59.98**	**2**	**0.000**
	Natura status	**11.89**	**1**	**0.001**	**6.37**	**1**	**0.012**	**33.90**	**1**	**0.000**	**201.72**	**1**	**0.000**	**72.95**	**1**	**0.000**
	Year x habitat	2.04	2	0.360	4.62	2	0.099	**6.10**	**2**	**0.047**	4.24	2	0.120	1.03	2	0.599
	Year x Natura	**31.16**	**1**	**0.000**	**7.40**	**1**	**0.007**	1.55	1	0.214	**14.78**	**1**	**0.000**	0.03	1	0.870
	Year x habitat x Natura	4.58	2	0.101	3.66	2	0.161	2.87	2	0.238	0.22	2	0.895	0.36	2	0.835
Abundance	Year	**7.83**	**1**	**0.005**	0.37	1	0.544	**23.28**	**1**	**0.000**	2.94	1	0.086	2.68	1	0.102
	Farmland habitat	0.57	2	0.754	**605.83**	**2**	**0.000**	**2114.25**	**2**	**0.000**	**223.72**	**2**	**0.000**	**57.51**	**2**	**0.000**
	Natura status	2.09	1	0.149	2.81	1	0.094	**15.01**	**1**	**0.000**	**165.11**	**1**	**0.000**	**63.00**	**1**	**0.000**
	Year x habitat	**8.77**	**2**	**0.012**	**12.66**	**2**	**0.002**	**8.18**	**2**	**0.017**	**7.40**	**2**	**0.025**	**6.43**	**2**	**0.040**
	Year x Natura	**8.24**	**1**	**0.004**	**5.01**	**1**	**0.025**	0.06	1	0.810	**15.87**	**1**	**0.000**	0.24	1	0.621
	Year x habitat x Natura	5.75	2	0.056	2.09	2	0.352	1.36	2	0.507	0.04	2	0.979	5.40	2	0.067

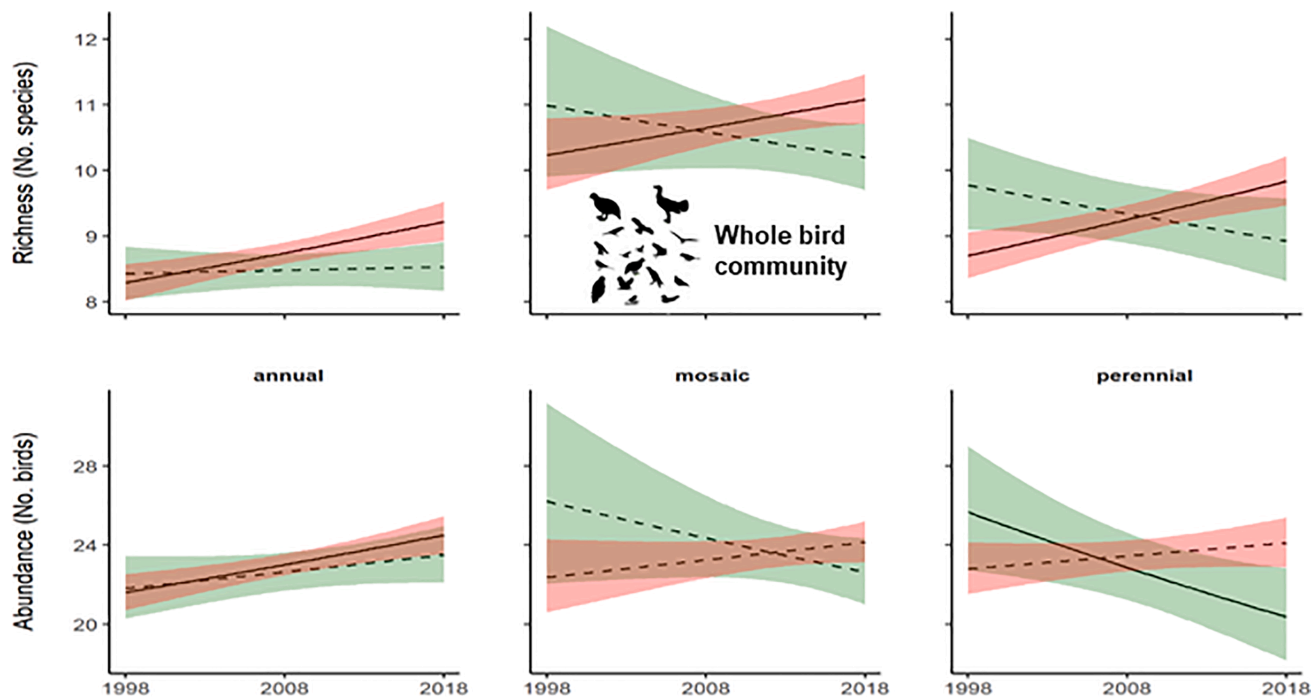

Fig. 3. Trends (±95% CI) in bird species richness and abundance of birds detected in sampling stations located in farmland habitat, after excluding species most likely using habitats other than agricultural but located nearby. Trends were depicted for the three farmland habitat categories considered (annual, perennial, and mosaic cropland) and for sites located inside (green) or outside (red) Natura 2000 areas. Trends differed inside and outside Natura 2000, and also among farmland habitat for bird abundance (Table 1). Significant trends are represented by solid lines, non-significant trends by dashed lines.

mainland Spain were also excluded (Princé et al., 2021). Selected stations were surveyed 5.72 years on average (±0.04 SE; median = 4). Overall, 690,690 records from 246 species were obtained (Appendix) after database curation. Out from these, 64,327 (9.8%) from 105 species (43%) most likely correspond to birds detected in non-agricultural habitats within stations (Appendix). Out of the remaining 141 species, 35 were included in the Farmland Bird Index and 28 were steppic birds. The database contains records for 48 threatened species, but 24 most likely correspond to birds detected in non-agricultural habitats. Only 7 species included in the Farmland Bird Index were also classified as threatened (Appendix).

3.2. Methodological consistency of temporal trend analyses

Trend analyses were consistent overall for TRIM models initially developed to analyse individual species' trends and GLMMs, more suited to analyse the community parameters of abundance and richness considered here (Fig. 2).

Comparison of results considering all species detected and excluding species than would have been using other habitats but that can be detected from nearby farmland sites also showed close agreement when considering all bird species (Fig. 2, upper). Negative trends were undervalued on average when using official (EU Farmland Bird Index) *vs.* ecological (steppic birds) criteria to classify birds as farmland-dependent, but direction of estimated changes were fairly coincident (Fig. 2, middle). Finally, while overall trend for all threatened birds resulted positive or neutral, trends for threatened farmland birds were strongly negative (Fig. 2, lower). Estimates of percent change of trends varied between c.a. +80% (abundance of threatened birds in annual crops inside Natura 2000) to −60/− 90% (threatened farmland birds in

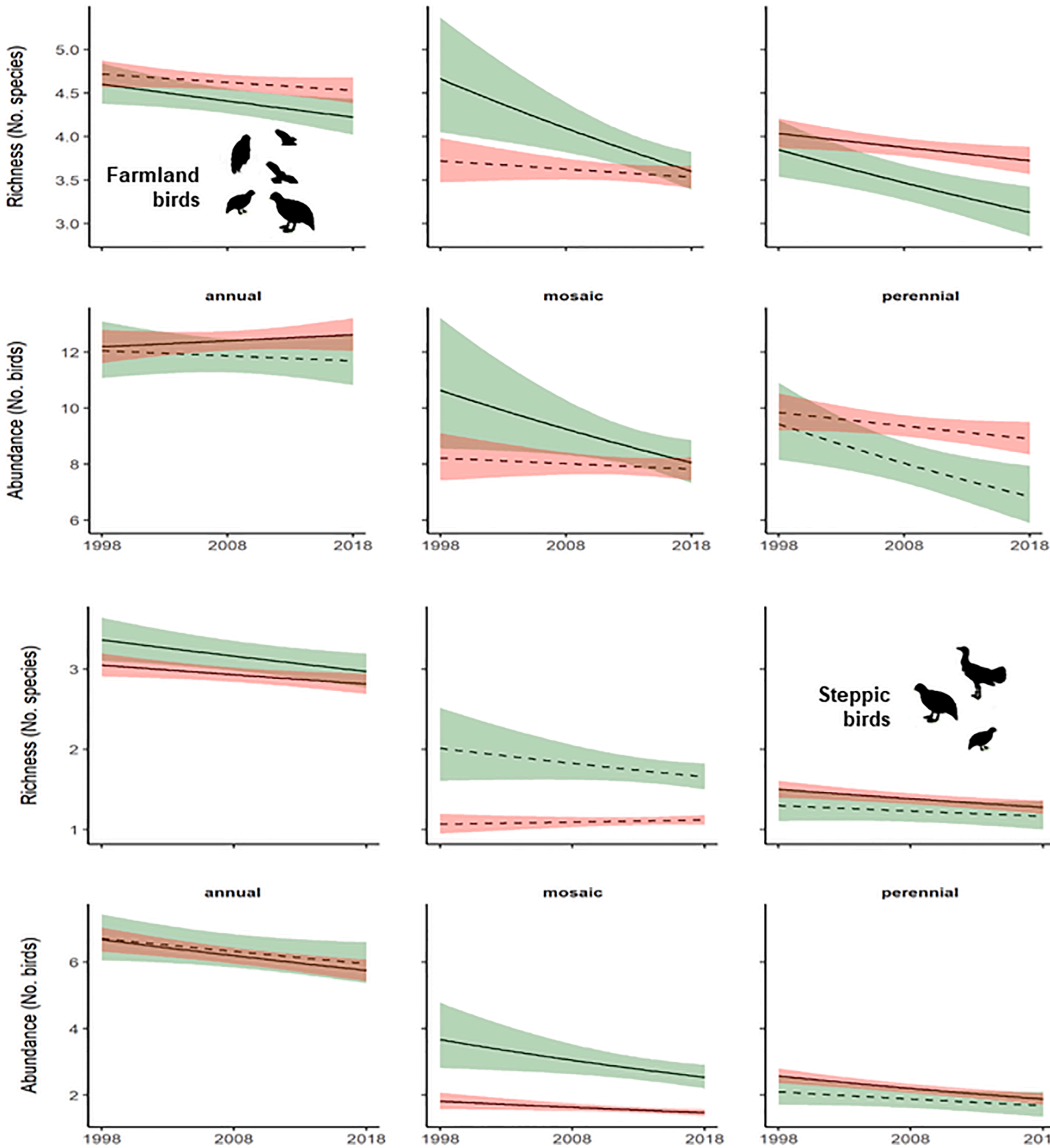

Fig. 4. Trends (±95% CI) in bird species richness and abundance of farmland birds detected in sampling stations located in farmland habitat. Trends for species officially considered as such are shown above and trends for steppic birds below. Trends were depicted for the three farmland habitat categories considered (annual, perennial, and mosaic cropland) and for sites located inside (green) or outside (red) Natura 2000 areas. Trends differed inside and outside Natura 2000 and/or among farmland habitats according to community parameter and bird group (Table 1). Significant trends are represented by solid lines, non-significant trends by dashed lines.

mosaic farmland inside Natura 2000) depending on bird group, habitat, Natura 2000 and modelling approach.

3.3. Habitat and Natura 2000 effects on trends of birds groups

Local bird species richness and abundance have changed in Spanish farmland throughout the 1998–2017 years of monitoring of the SACRE program, and changes have varied among bird groups, habitat types and location of sampling points inside or outside the Natura 2000 network (Table 1). Considering all species, trends have been positive overall in annual croplands and outside Natura 2000 sites (Table 1, Figs. 2, 3). Trends inside Natura 2000 have been negative overall, especially for perennial crops (Figs. 2, 3).

Richness and abundance of birds officially associated to agricultural habitats have remained stable on average, with a significant interactive effect of the Natura 2000 network (Table 1). Trends were more negative inside than outside Natura 2000 sites, especially in perennial and mosaic cropland (Fig. 4). Trends for steppic birds were negative overall, and

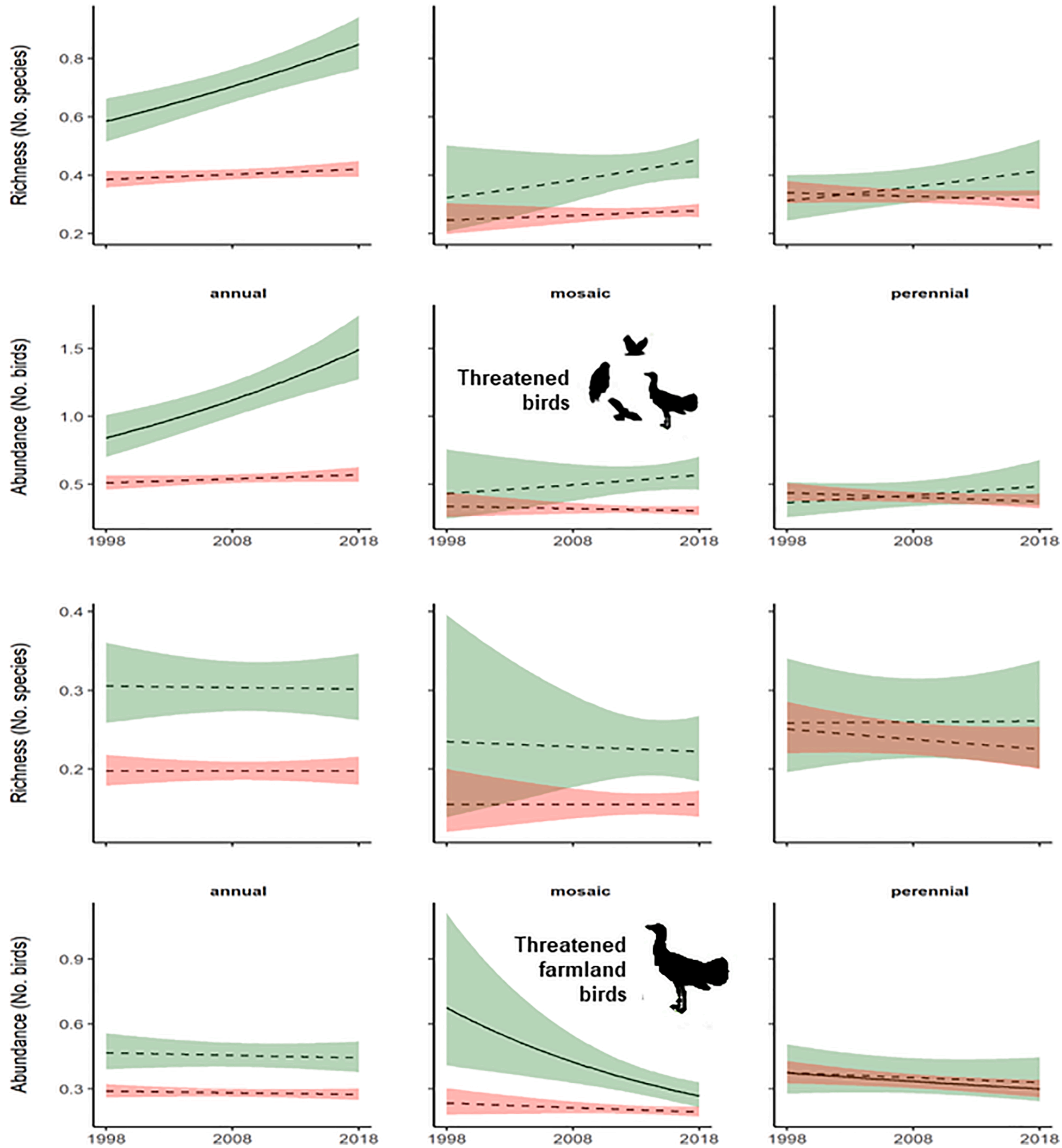

Fig. 5. Trends (±95% CI) in bird species richness and abundance of threatened birds detected in sampling stations located in farmland habitat. Trends for all threatened birds detected are shown above and trends for threatened farmland birds below. Trends were depicted for the three farmland habitat categories considered (annual, perennial, and mosaic cropland) and for sites located inside (green) or outside (red) Natura 2000 areas. Trends differed inside and outside Natura 2000 and/or among farmland habitats according to community parameter and bird group (Table 1). Significant trends are represented by solid lines, non-significant trends by dashed lines.

more inside than outside Natura 2000 sites (Table 1, Fig. 4). Farmland habitat interacted with trends, that were stepper in perennial and mosaic croplands than in annual crops (Fig. 4).

Threatened species showed stable trends outside and increasing trends inside Natura 2000, especially in annual crops (Table 1, Fig. 5). This trend was however not significant when considering threatened farmland birds only, and even significant negative trends were detected in mosaic landscapes inside Natura 2000 sites (Table 1, Fig. 5).

4. Discussion

Site-based analyses confirmed overall trends detected by species-based official reports, and complement them by suggesting additional reasons for failures at reverting negative trends in farmland biodiversity (Díaz et al., 2021). In particular, site-based analyses at the point count scale allowed to identify the farmland habitats where declines were stepper, namely perennial and mosaic crops, as well as positive trends of overall bird communities and of threatened birds in farmland habitats that cannot be detected with the official species-based approach.

Positive trends for overall bird communities occurred in all types of agricultural habitat and both inside and outside the Natura 2000 network, but especially outside it. Bird increases cannot then be attributable to differences in the management of different types of agricultural habitat or to the protection of these habitats by the Natura 2000 network. In fact, negative trends for the bird species more linked to agricultural habitats, and positive trends for some threatened species, suggest that this increase can only be attributed to a generalized increase of generalist species, or to a greater occupation of agricultural habitats by these habitat generalists (Filippi-Codaccioni et al., 2010). These results cannot be attributed to records of birds from census points that were not using farmland but nearby habitats nor to methodological bias, as results were consistent among methods and when considering restricted datasets. Hence, we conclude that Spanish agricultural habitats were increasingly occupied by a variety of non-farmland birds. This unexpected trend, that cannot be detected with the usual species-by-species approach, may parallel the increased use of urban habitats by many bird species in Europe (Møller and Díaz, 2018), and it is worth analyzing its causes and potential consequences in greater depth.

Consistent declines of bird communities associated to Spanish farmland varied in intensity among habitats, location inside or outside Natura 2000, and relevant bird groups, with steeper declines for the group of specialist steppic birds in perennial or mosaic croplands located inside rather than outside the Nature 2000 network. Negative trends have already been reported for some regions (e.g. Palacín and Alonso, 2018), and are generally related to the strong increase in the intensification of the agriculture in the last decades (Traba and Morales, 2019). In fact, the agri-environmental schemes developed to reduce intensification to favor steppic birds have been demonstrated as generally effective at local scales (Kleijn et al., 2006; Concepción and Díaz, 2011, 2019; Concepción et al., 2012, 2020; Tarjuelo et al., 2021). Our results showed that local success of CAP measures to reduce intensification have not translated into wide-scale positive population trends in Spain, however. Causes for this failure would be low levels of adoption by farmers (Pardo et al., 2020) that did not eliminate landscape-scale constraints to overall effectiveness (Concepción et al. 2012; Díaz et al. 2021), wide-scale CAP support to farming practices with demonstrated negative effects for farmland specialists (e.g. perennial crops or afforestations; Santos et al., 2006; Reino et al., 2009; Santana et al., 2014, Díaz and Concepción, 2016; Concepción and Díaz, 2011, 2019), or landscape simplification due to irrigation, urban sprawl or expansion of intensive perennial crops inside Natura 2000 sites (Gameiro et al. 2020; Concepción 2021). Stronger negative trends in cropland with perennial crops and inside Natura 2000 sites found here supported these potential causes, although further local analyses based on proper study designs (i.e. BACI designs; Díaz and Concepción, 2016 and references therein) would be needed to demonstrate cause-effect relationships.

Contrasting with these negative trends, threatened birds have experienced increasing or stable trends in Spanish farmland sites, that were concentrated in annual croplands located inside Natura 2000. The Natura 2000 network seems to have been effective to protect threatened birds, in spite of some regional evidences of lack of effectiveness (Palacín and Alonso, 2018). Positive effects for threatened flagship species but not for common farmland birds linked to cereal crops have also been found recently by Santana et al. (2014). Investment in flagship species have led to general increases in their threatened populations in the last decades (de Juana, 2004; Inger et al., 2015), but it does not ensure the conservation of the overall steppe bird assemblage (Caro, 2010). It should be necessary to broaden the focus of conservation measures applied in Natura 2000 sites in order to protect not only threatened but also a wider range of farmland birds (Santana et al., 2014). Preventing afforestations, perennial crops and irrigations would be a first step, followed by regionally-targeted conservation measures ensuring enough farmers' uptake (Kleijn et al., 2006; Díaz et al., 2021). Performance evaluation and subsequent adaptation based on the results obtained must go along with the implementation of conservation tools (Díaz and Concepción, 2016; Concepción and Díaz 2019; Concepción et al., 2020).

Performance evaluation implies adequate monitoring of farmland bird communities at site- and landscape-scales (Portaccio et al., 2021; Princé et al., 2021). Broad-scale, citizen science programs such as the European bird monitoring schemes (Voříšek et al., 2010; Brlík et al. 2021) can be useful for this purpose in spite of being designed for monitoring species' rather than site trends (Pellissier et al., 2013, 2020; Princé et al., 2021). In fact, site- and habitat-based analyses of these datasets can be useful to detect whether trends of farmland birds could be affected by land-use changes linked to CAP instruments (e.g. expansion of irrigation or perennial crops in annual croplands; Gameiro et al., 2020) and evaluate the overall contribution of spatially explicit conservation strategies such as the Natura 2000 network (Portaccio et al., 2021; Princé et al., 2021). Further causal analyses based on monitoring data at the scale of particular Natura 2000 sites (e.g. Concepción and Díaz, 2019; Concepción et al., 2020; Gameiro et al., 2020) cannot generally be done using broad-scale European bird monitoring programs such as SACRE, however. The reason is its thin spatial coverage (only 20 samples per 100 km^2), that usually implies low sample sizes at this site scale. For the Spanish case study, sampling density was 0.9 sampling points/Natura 2000 site (range: 0–148) and 0.8 points/100 km^2 (range 0–20); n = 1468 sites. Monitoring protocols designed in parallel to CAP measures and financed by CAP funds to ensure its implementation at farm scales can fill this key monitoring gap (Kleijn et al., 2006; Díaz et al., 2021; Pe'er et al., 2022), although these protocols should be necessarily constrained to evaluate the specific targets of measures rather than to monitor population trends (Pe'er et al., 2022). A better combination of citizen science programs with cause-effect, finer-scale studies will help disentangle the causes of the observed patterns to develop better and more efficient conservation recommendations.

5. Author statement

Mario Díaz: study design, database curation, data analyses, writing-original draft, writing. Pablo Aycart: data analyses, writing-review & editing; Anna Ramos: database curation, data analyses, writing-review & editing; Ana Carricondo: study design, validation, writing; Elena D. Concepción: study design, database curation, data analyses, validation, writing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2022.109051.

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