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Spatial and thematic bias in the scientific literature on farmland birds across the globe

J. GUERRERO-CASADO[1]*, Ł. DYLEWSKI[2], Z. M. ROSIN[3], P. SKÓRKA[4], A. WUCZYŃSKI[4], & M. TOBOLKA[2,5]**

[1]*Departamento de Zoología, Universidad de Córdoba. Edificio Charles Darwin, Córdoba, Poland,* [2]*Department of Zoology, Poznań University of Life Sciences, Poznań, Spain,* [3]*Department of Avian Biology and Ecology, Faculty of Biology, Adam Mickiewicz University, Poznań, Poland,* [4]*Institute of Nature Conservation, Polish Academy of Sciences, Kraków, Poland, and* [5]*Konrad Lorenz Institute of Ethology, University of Veterinary Medicine Vienna, Wien, Austria*

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Abstract
The global biodiversity crisis and constantly growing human impact on the natural environment call for more evidence where conservation actions are the most urgent. As the agricultural lands are under increased pressure of growing human food needs here the literature survey on farmland bird conservation (FBC) was conducted to reveal geographical distribution in research intensity, the topics addressed and to identify potential drivers for the worldwide scientific effort. The Scopus database search has revealed 2290 papers dedicated to FBC from the period 1990–2020. The distribution was spatially uneven with most papers published in Western Europe and North America. Scientific collaboration was also spatially biased in favor of countries located close to each other and having high scientific capacity. The analysis also revealed 139 terms representing main topics raised in FBC research. The number of FBC papers per country was positively correlated with Gross Domestic Production (GDP), the total number of scientific papers, and number of threatened species, and negatively with the GDP from agricultural production, whereas it was not related to area of agricultural lands or bird species richness. Spatial and thematic biases in studies of farmland birds may have important consequences since uneven scientific evidence constrains development of proper conservation solutions and limits their implementation. We conclude that research on FBC should be globally coordinated and flexible enough to undertake burning conservation problems adjusted to regional differences in agriculture, socio-economy, and bird diversity.

Keywords: *Agroecosystems*, *bird conservation*, *biodiversity conservation*, *systematic review*, *scientific production*

Abbreviation: Farmland bird conservation (FBC), Akaike information criterion (AIC), Gross Domestic Product (GDP), research and development (R&D), Common Agricultural Policy (CAP), variance inflation factor (VIF)

Introduction

The global agricultural land (croplands and pastures) area, stable for several decades (Winkler et al. 2021), started expansion (Rudel et al. 2009) and currently constitutes approximately 50% of the land surface in 2021 (FAO 2021). This expansion, together with the intensification of crop production on existing agricultural lands, is causing progressing biodiversity loss (Laurance et al. 2014; Li et al. 2020; Jeanneret et al. 2021). The associated destruction of natural and semi-natural habitats coupled with climate change results in substantial species extinction and ecosystem functioning degradation worldwide (Eriksson 2021; Raven & Wagner 2021).

Correspondence:*J. Guerrero-Casado, Department of Zoology, Poznań University of Life Sciences, Wojska Polskiego 71C, Poznań 60-625, Spain. Email: guerrero.casado@gmail.com; b32gucaj@uco.es
**M. Tobolka, Departamento de Zoología, Universidad de Córdoba. Edificio Charles Darwin, Campus de Rabanales, Córdoba 14071, Poland. Email: tobolkamarcin@gmail.com; marcin.tobolka@up.poznan.pl

However, changes in agricultural practices and the general land use are not evenly distributed across the globe, nor is the significance of agricultural areas for biodiversity. This variation is mainly driven by regional differences in economy and history of land use (Bruinsma 2003). In developed countries of Europe and North America, food production increases mainly via agriculture intensification, whereas to cover the increase in food demands, new agricultural lands are being intensively established in Africa, South America and South-East Asia mainly through deforestation (Güneralp et al. 2020; Liu et al. 2020; Winkler et al. 2021). Moreover, low productive agricultural lands disappear at the expense of built-up areas, particularly in developing countries, such as China, India, or Brazil (Tilman et al. 2011; Güneralp et al. 2020; Liu et al. 2020; Winkler et al. 2021). If the recent global trends continue, food demands will increase more within poorer regions than in relatively rich ones (Tilman et al. 2011).

Traditional heterogeneous agricultural landscapes are associated with high farmland fauna diversity (Morelli 2018; Eriksson 2021). Europe and North America are particular examples where farming is located within protected areas, and many agri-environmental schemes have been introduced (Batáry et al. 2015; Morelli 2018; Pavlacky et al. 2022), and the effects of agricultural intensification on farmland fauna diversity are well documented there (Donald et al. 2001). Whereas in other parts of the globe where agricultural production is being intensified, research on its influence on fauna diversity is often scarce, and natural and semi-natural habitats in farmlands are rarely protected (Fox et al. 2017; Liu et al. 2019; Hossard & Chopin 2019). Wright et al. (2012) showed that 22% of all threatened or near-threatened bird species in developing countries use artificial landscapes, primarily agricultural ones. They identified nearly 30 threatened bird species dependent on low-impact agriculture in the developing world.

Many organisms inhabiting farmland are highly endangered species undergoing rapid population declines (e.g., Wretenberg et al. 2007; Stanton et al. 2018). Among them, birds are an important component of farmland biodiversity and play numerous ecological functions (Gottschalk et al. 2010; Flohre et al. 2011; Fahrig et al. 2015; Pustkowiak et al. 2021). They are seed dispersers (Breitbach et al. 2010), drive nutrient recycling (Navedo et al. 2015), and act as insect controllers (Geiger et al. 2010; Díaz-Siefer et al. 2022), but are also considered pests sometime (Montras-Janer et al. 2020). Therefore, birds are often regarded as indicators of ecosystem health (Gregory et al. 2004), and their decline imposes substantial risks on agricultural ecosystems (Donald et al. 2001). Additionally, birds are of interest to many scientists and one of the best-studied animal groups in agricultural areas. Changes associated with agriculture, such as the reduction of semi-natural habitats (e.g. Fuller et al. 2004; Newton 2004), crop modernization (e.g. Šálek et al. 2021) and increased use of insecticides and fertilizers (e.g. Chamberlain et al. 2000; Stanton et al. 2018) have been identified as the greatest global threats to birds (Rigal et al. 2023), especially for insectivorous species. Having a broad range and a migratory yearly cycle, they experience various conditions and mirror changes occurring worldwide, what makes this group suitable for comparisons across different geographical regions.

Coverage of topics and problems in the research on farmland bird conservation (hereafter FBC) is highly uneven. The majority of studies on farmland bird diversity have focused on factors acting at large spatial scale, underestimating other aspects like small-scale elements of the landscape (Pustkowiak et al. 2021) or rural settlements (Rosin et al. 2020, 2021) that also shape changes in bird populations. Moreover, studies on farmland birds mostly focus on the breeding period (Gregory et al. 2004; Stanton et al. 2018). Although it is a particularly important part of the year cycle, the autumn and spring migration as well as wintering are critical phases for population dynamics due to the highest mortality during these periods (Klaassen et al. 2014). The role of agricultural lands for migrating birds is vital but not fully assessed (Blount et al. 2021). It becomes more significant, especially as agriculture undergoes intensive development in areas of massive bird migration, such as the Middle East, North Africa, and the entire Mediterranean region (Lofgren & Richards 2003; Nin-Pratt et al. 2017).

Furthermore, a challenge lies in the regional disparities in biodiversity patterns influenced by a range of social and ecological factors (Tryjanowski et al. 2011; Reif 2013). It can be presumed that the extent of research on FBC varies significantly worldwide. However, as of now, no studies have been conducted to investigate the spatial bias in the global research effort on FBC and its underlying drivers. Therefore, the aim of this paper is to test (i) how the intensity of FBC research is distributed worldwide, (ii) which socio-economic and agriculture-related variables explain the scientific effort on farmland birds; and finally, (iii) to point out the geographic areas that should be more intensively studied to enrich our knowledge about the farmland birds and help to protect them more effectively.

Methods

Literature search

To establish a replicable search protocol, articles about birds in farmland in the period 1990–2020 were searched in August 2021 in the Scopus database. We selected this period because a majority of farmland bird conservation studies has been published since 1990 worldwide (see the results). The following terms in the title or abstract or keywords were selected: (*agriculture* OR *farmland* OR *agricultural)* AND *bird* AND *conservation*. The term "conservation" was included to select those papers dealing, at least at some point, with bird conservation in agricultural lands (i.e., impacts of agricultural activities on bird populations, testing conservation measures, or the importance of agricultural areas for bird conservation). At the first step, 2,976 documents were obtained. Subsequently, these papers were validated whether they were indeed dedicated to farmland birds. Farmland birds are defined here as bird species using farming areas during at least one part of the year-life cycle, e.g., breeding, wintering, or stopover. The following papers were excluded from the collection: those dealing with poultry (only genetics, diseases of birds bred in captivity for food production, chickens, hens, domestic turkeys, ducks, or geese); dedicated to other groups of farmland animals (e.g., insects, mammals, amphibians); dealing with natural grasslands not used as agricultural production; not particularly dedicated to farmland, in which the farmland areas were just mentioned as potential or real threat factor; papers on other groups of birds in which farmland birds were neither listed nor tested or reported. Articles not particularly dedicated to farmland were included in the collection if they met one of the following assumptions: the agricultural areas were tested as a factor, driver, e.g., tropical birds in forests vs. farmlands, or waterbirds in water ecosystems vs. farmlands; when the farmland was a foraging ground for birds not necessarily considered as farmland birds (e.g., geese, ducks, cranes); about agroforestry and birds; when some ecological or biological phenomenon were compared in different land uses including agricultural areas. In all cases, when it was not clear from the title and keywords, the abstract was checked if the paper was indeed about farmland birds and the effects of farmland on birds. After this step, 2,290 articles were selected and used in the subsequent analyses. Finally, to compare the temporal tendency of papers on FBC with papers dealing with bird conservation in general, during additional searching, the terms *bird* AND *conservation* were used in the title or abstract or keywords during the same period (1990–2020).

Bibliometric analysis

Bibliometric analysis was conducted using the software VOSviewer version 1.6.17 (van Eck & Waltman 2021). Firstly, the analysis of the co-authorship according to the author's country affiliation was conducted, which allowed, on the one hand, to rank countries according to the number of published articles on FBC, and on the other hand, to assess the strength of the collaboration among countries. The strength of the link between two countries indicates the number of publications that these two countries have co-authored, whereas the total link strength of a country represents the total strength of the co-authorship links of a given country with all other countries (van Eck & Waltman 2021). For this purpose, only countries with more than five articles were selected, since the strength of collaboration between countries is difficult to assess with fewer articles. VOSviewer generates distance-based visualizations of networks of countries, in which closely related countries are positioned close together (Freire & Nicol 2019). A closely linked set of items (countries) were grouped in clusters which is useful to understand the structure of the network. Although the author's affiliation does not always correspond with the study area, and one paper can have several authors from different countries, it can reflect a given country's conservation research capacity (Pototsky & Cresswell 2020), and it has been used as a good approach in some bibliometric articles on biodiversity conservation (e.g., Westgate et al. 2015; Guerrero-Casado & Monge-Nájera 2023). Moreover, the countries were grouped according to their geographical region following the classification established by Scimago Journal & Country Rank: Africa, Asia, Eastern Europe (from Poland and Czech Republic to Russian Federation), Latin America, Middle East, Northern America, Pacific Region, and Western Europe.

VOSviewer was also used to identify the co-occurrence of terms (which can be considered as topics) in the article title and keywords. Due to the lack of author keywords information available from several journals (432 documents out of 2,290), an analysis joining the title and the keywords provides better results. Synonymic words were merged, re-labeled and counted as one (e.g., agri-environment measures, agri-environment scheme, and AES). Those terms repeated at least ten times were selected for this analysis. The terms used in the literature search (agriculture, farmland, agricultural, bird and conservation) were excluded, since they are present in all the articles and therefore, they are unuseful for establishing networks based on co-occurrence. Of the 232 terms that meet these criteria, the network map was created with items with the top 60% relevance scores ($n = 139$ terms) following the VOSviewer's default option. Terms with high relevance scores represent specific topics covered by the text data, while general terms (e.g., conclusions, results, review, factors) with a low relevance score tend not to be representative of any specific topic (van Eck & Waltman 2021). These 139 terms were also grouped in clusters.

Relationship between the number of papers on farmland birds and the selected explanatory variables

Some potential explanatory variables for the number of papers on FBC per country (response variable) were obtained from the World Data Bank. The first set of variables were some previously identified as significant predictors of scientific production (Wilson et al. 2016; Vinkler 2018; Allik et al. 2020; Guerrero-Casado & Monge-Nájera 2021). These variables were the Gross Domestic Product per cápita (GDP per cápita), and the GDP expenditures on research and development (R&D) expressed as a percent of GDP (R&D expenditure as % GDP). In this first set of variables, the scientific production in Scopus per country during the period 1996–2020 was obtained from the Scimago Journal & Country Rank. The second set of variables was those related to agriculture's importance, particularly the area devoted to agriculture in relative terms (%) and agriculture value added (% of GDP). For the variables GPD per cápita, R&D expenditure, agricultural land, and agriculture added value, an average value during the study period (1990–2020) was calculated. Finally, the number of threatened bird species according to the International Union for Conservation and Nature (IUCN) criteria, and the total number of bird species per country (BirdLife International 2021) were also included as the number of species per 10,000 km^2.

Statistical analysis

Prior to the analysis, a Pearson correlation matrix was created to check the correlation between the explanatory variables, including also the response variable, i.e. log-number of papers on farmland birds per 1 million inhabitants. Multiple regression models were performed to test the association between the number of documents on FBC per 1 million inhabitants (log-transformed) and the explanatory (independent) variables: log-GPD per cápita (US Dollars ($)), R&D expenditure (%), the log-n° of papers in Scopus per 1 million of inhabitants, the agricultural land (%), the agricultural added value (%), the number of threatened bird species per 10,000 km^2, and the log-number of bird species per 10,000 km^2. Some variables were log-transformed to get normality in the residuals and reduce impact of detached data points (skewness). All possible combinations among independent variables were performed. The variance inflation factor (VIF) was used to check for collinearity among the predictors, and those predictors with VIF > 3 were discarded (Zuur et al. 2010). The model selection was based on Akaike information criterion (AIC), the models with the lowest AIC being the best (Burnham et al. 2011). As a rule, a $\Delta AICi < 2$ suggests substantial evidence for the model (and, therefore, for the variables included). The normality of the model residuals was visually confirmed. Finally, the residuals of the full model without correlated variables (VIF < 3) were plotted to explore the residuals variation in the response for individual countries that remained after accounting for the predictor variables. All the statistical analyses and graphs were conducted using the InfoStat 2020 version and R software.

Results

General description of published papers

The yearly number of papers on FBC increased during the study period, following the same tendency in papers dealing with bird conservation in general (t-test to compare two slopes $t = 1.941$; $p = 0.067$), and both variables were highly correlated (estimate = 1.17 ± 0.04; $t = 27.75$; $p < 0.0001$, Fig. S1). In 1990, only seven FBC articles were published, whereas 177 articles were published in 2020. According to the decade, 181, 679, and 1,430 articles were published in the 1990s, 2000s and 2010s, respectively. When considering records of all co-authors' affiliations, the increase differed significantly between regions, i.e., it was significantly more intense in Western Europe and North America than in others (estimate = 60.87 ± 4.53, $t = 13.43$ and estimate = 29.71 ± 4.53, $t = 6.56$ respectively, $p < 0.0001$ in both cases, Figure 1).

The United States, United Kingdom, Spain, Australia, Germany, France, Canada, Netherlands,

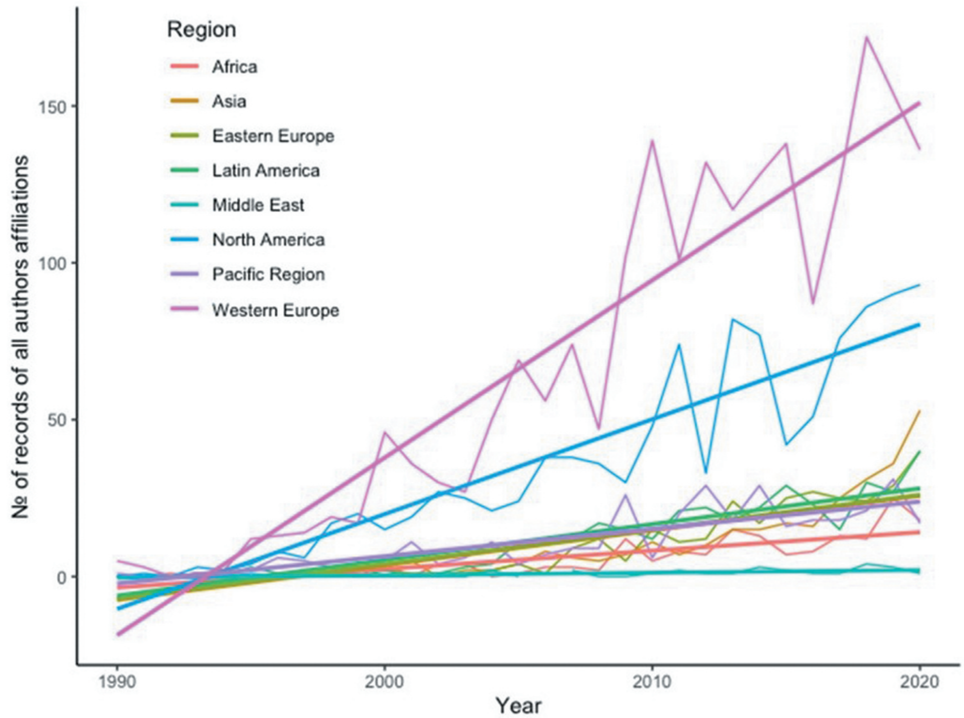

Figure 1. The number of papers on farmland birds published per year, grouped by geographical regions according to all authors' affiliations (number of records is higher than the exact number of papers due to multiple co-authors).

Italy, and Sweden were the top-10 countries for the number of articles on farmland birds (Figure 2a). Conversely, most African and Middle East countries had a low number of papers (Figure 2a,b). Some large and populated countries, such as China, Russia, Brazil, India or Kazakhstan, had a low number of papers concerning their population and a large area of agricultural land (Figure 2b,c). Conversely, smaller countries such as Switzerland, Netherlands, Denmark or Costa Rica showed a high number of papers per agricultural area (Figure 2c). The number of documents on FBC related to bird species richness was low in African countries and it was much greater in Europe, North America and Australia (Figure 2d).

Co-authorship analysis

The co-authorship analysis grouped the countries into six clusters (Figure 3). Roughly, the cluster-1 (red) was formed mainly by countries of North America and Latin America; the cluster-2 (green) by countries of Asia and the Pacific Region; the cluster-3 (dark blue) by countries of Western Europe and some countries of other regions; the cluster-4 (yellow) only by countries of Europe; the cluster-5 (purple) by some countries of Western Europe and Africa; and the cluster-6 (orange) by countries of Eastern Europe (Figure 3). The United Kingdom and the USA were the countries with the greater total strength link.

The number of papers per geographical region showed that Western Europe ($n = 1528$) is the region that accumulated most documents on FBC, followed by North America ($n = 682$) (Fig. S2). Conversely, Africa ($n = 135$) and the Middle East ($n = 25$) are the regions with the lowest number of papers. As Figure 4a shows, the number of papers per 1 million inhabitants is low in countries of Africa, Asia and the Middle East. Similarly, Figure 4b shows that many countries of Africa and Asia have low numbers of papers in relation to their agricultural area (Figure 4b).

Co-occurrence of topics

The analysis of the co-occurrence of the terms (topics) in the article title and keywords showed that these terms can be grouped in four clusters (Figure 5). The custer-1 (red) included terms more related to ecology of birds (i.e., habitat use, heterogeneity, habitat loss, habitat suitability, landscape composition, land-sharing, land-sparing, forests birds) and terms related to tropical environments, such as coffee, oil palm, and the name of some tropical countries; the cluster-2 (green) included terms related to grasslands, meadows, their

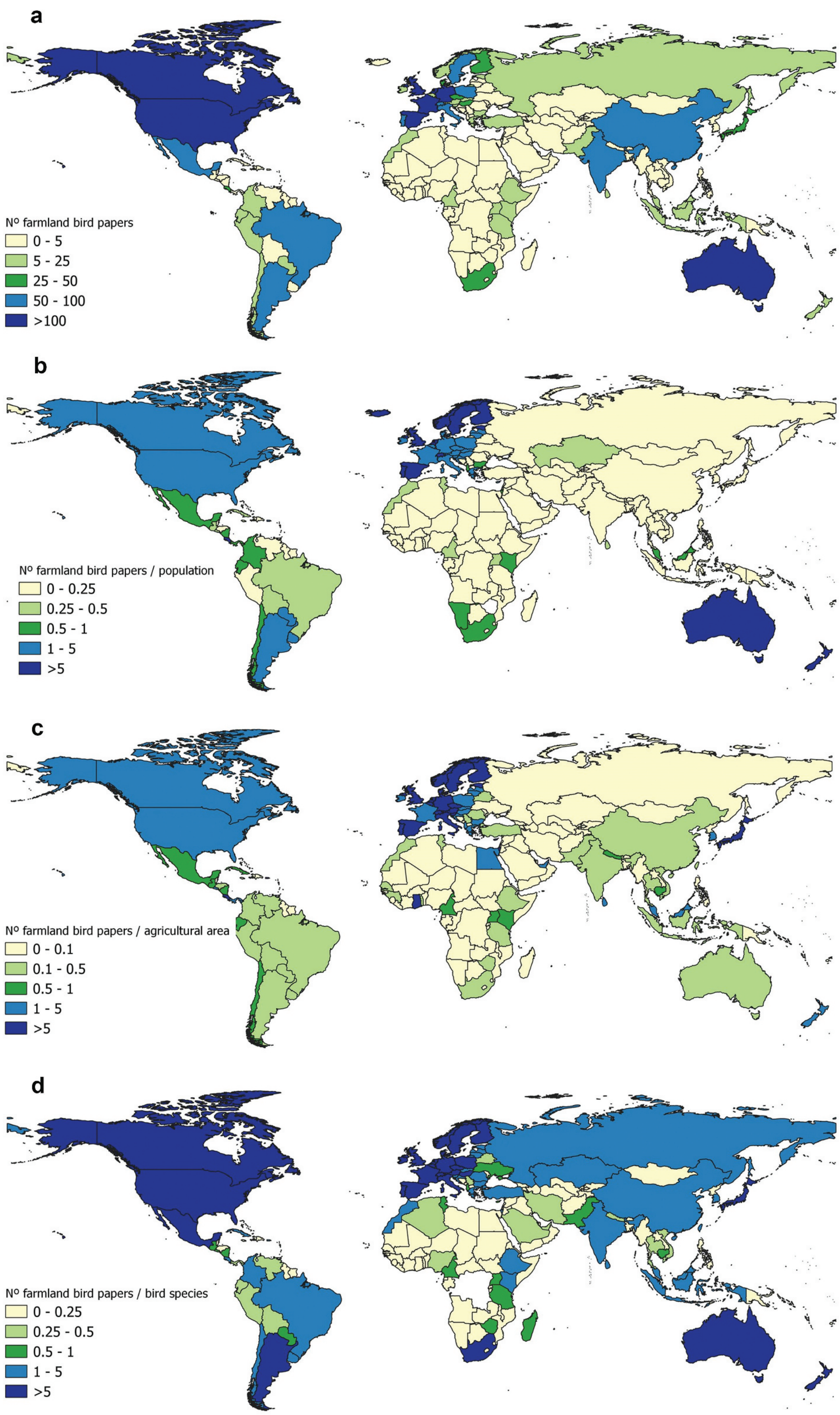

Figure 2. (a) The number of papers on farmland birds in each country during the period 1990–2020 according to the authors' affiliation country; (b) the number of papers on farmland birds per 1 million inhabitants; (c) the number of papers on farmland birds per 10,000 km^2 of agricultural area in each country; (d) the number of papers on farmland birds per bird species richness.

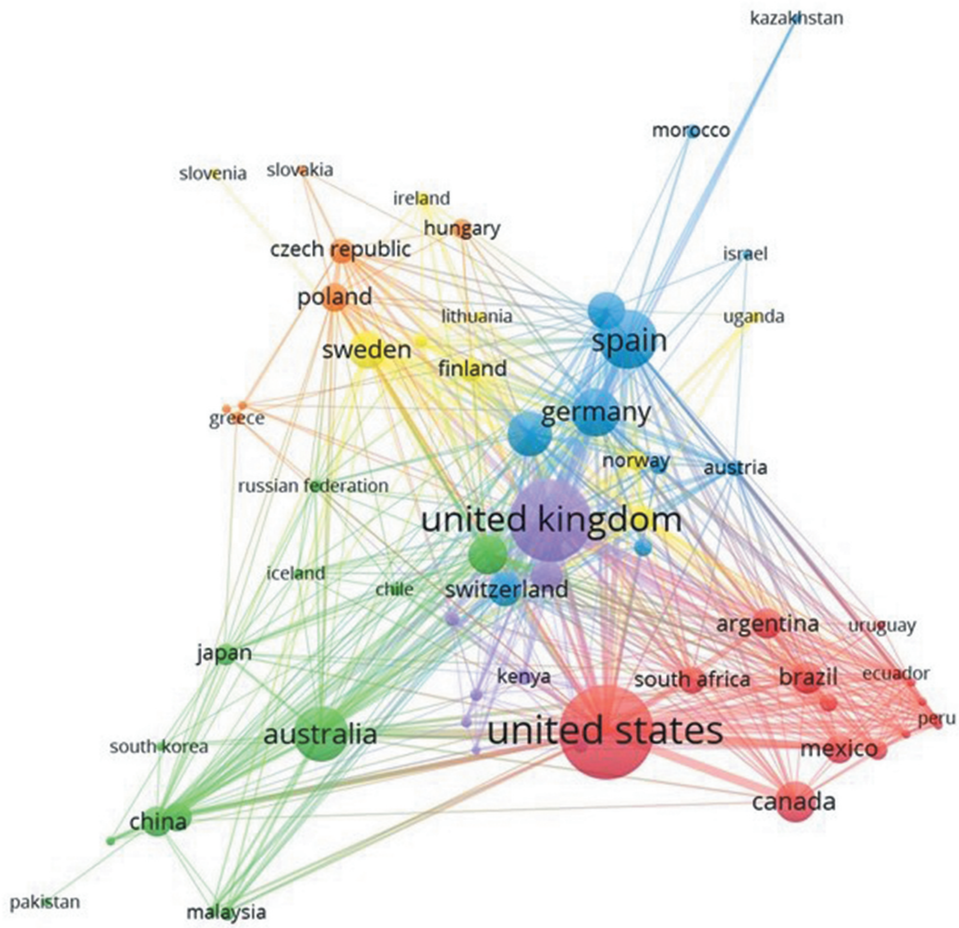

Figure 3. Network map created by VOSviewer based on co-authorships. The size of the circles is proportional to the number of papers. The different colours illustrate the different clusters in which the countries are grouped. Only countries with more than 5 papers are shown ($n = 63$).

management, and the species most associated to these habitats; the cluster-3 (blue) included the name of some countries of Europe and some specific topics (e.g., CAP, land abandonment or population trends); and cluster-4 (yellow) was related to waterbirds and wetlands, including also rice fields, crop damage, pesticide and migration. "Climate change", "heterogeneity", "habitat use" or "behaviour" were terms located in the center of the network maps, which suggests that they are topics of prime importance (Figure 5).

Effect of the explanatory variables on the number of papers on farmland birds

The Pearson correlation matrix (Table S1) showed that the number of papers on farmland birds per 1 million inhabitants was positively correlated ($p \leq 0.05$) with R&D expenditure (%), log GDP-per-capita and the log n°papers in Scopus per 1 million inhabitants, which were also intercorrelated among them. The agricultural added value (%) was negatively associated with the number of papers on farmland birds as well as with the R&D expenditure (%), log GDP-per-capita and the log-n°papers in Scopus per 1 million inhabitants (Table S1).

The best model included the following variables: log-n°papers in Scopus/1 million inhabitants, log-Bird Species/km^2, agriculture added value (% GPD), and the agricultural area (%). The best candidate model (lowest AIC) included only the variables log-n°papers in Scopus/1 million inhabitants and log-Bird Species/km^2, although the agriculture added value (% GPD) and the agricultural area (%) were also included in other candidate models (ΔAIC < 2) (Tables I and II). However, only the log-number of papers in Scopus showed an important estimate value and a clear relationship with the response variable (Tables I and II; Figure S3).

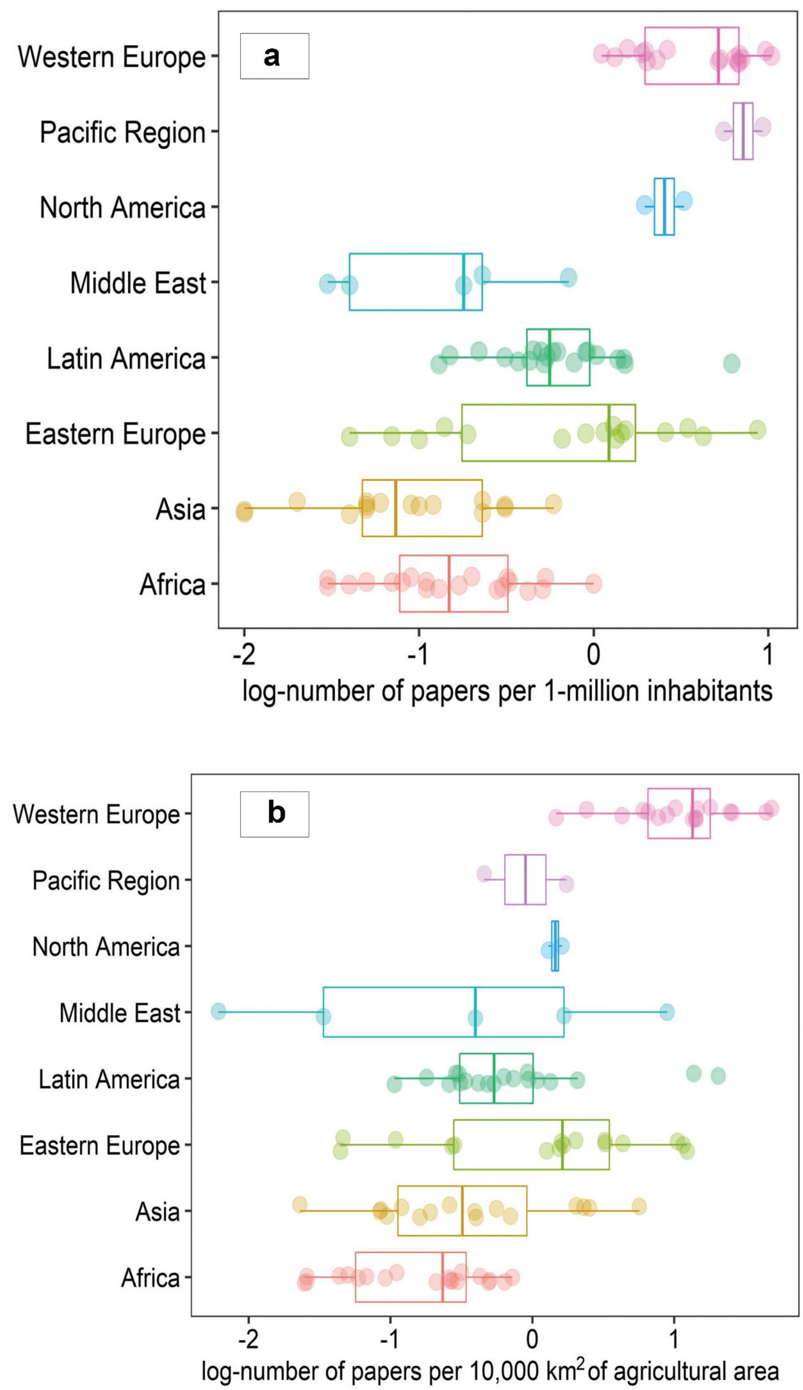

Figure 4. (a) Density-point graph showing the log-number of papers per 1 million inhabitants per country grouped by geographical regions. (b) Density-point graph showing the log-number of papers per 10,000 km^2 of agricultural area per country grouped by geographical regions. Box indicates 25%–75% quantile interval and whiskers indicate first and fourth quantile range, respectively.

The analysis of the residuals of the full model, which included the variables log-papers in Scopus/1 million inhabitants, log-Bird Species/km^2, agriculture added value (% GPD), and the agricultural area (%), allows to identify those countries with a higher or lower number of papers on FBC in relation to the explanatory variables (Fig. S4 and Figure 6), that is, higher or lower scientific production than expected, respectively. Some countries of the Middle East (Iran, Saudi Arabia, Israel, and the United Arab Emirates), Asia (South Korea, Bangladesh, Thailand, and the Philippines) and

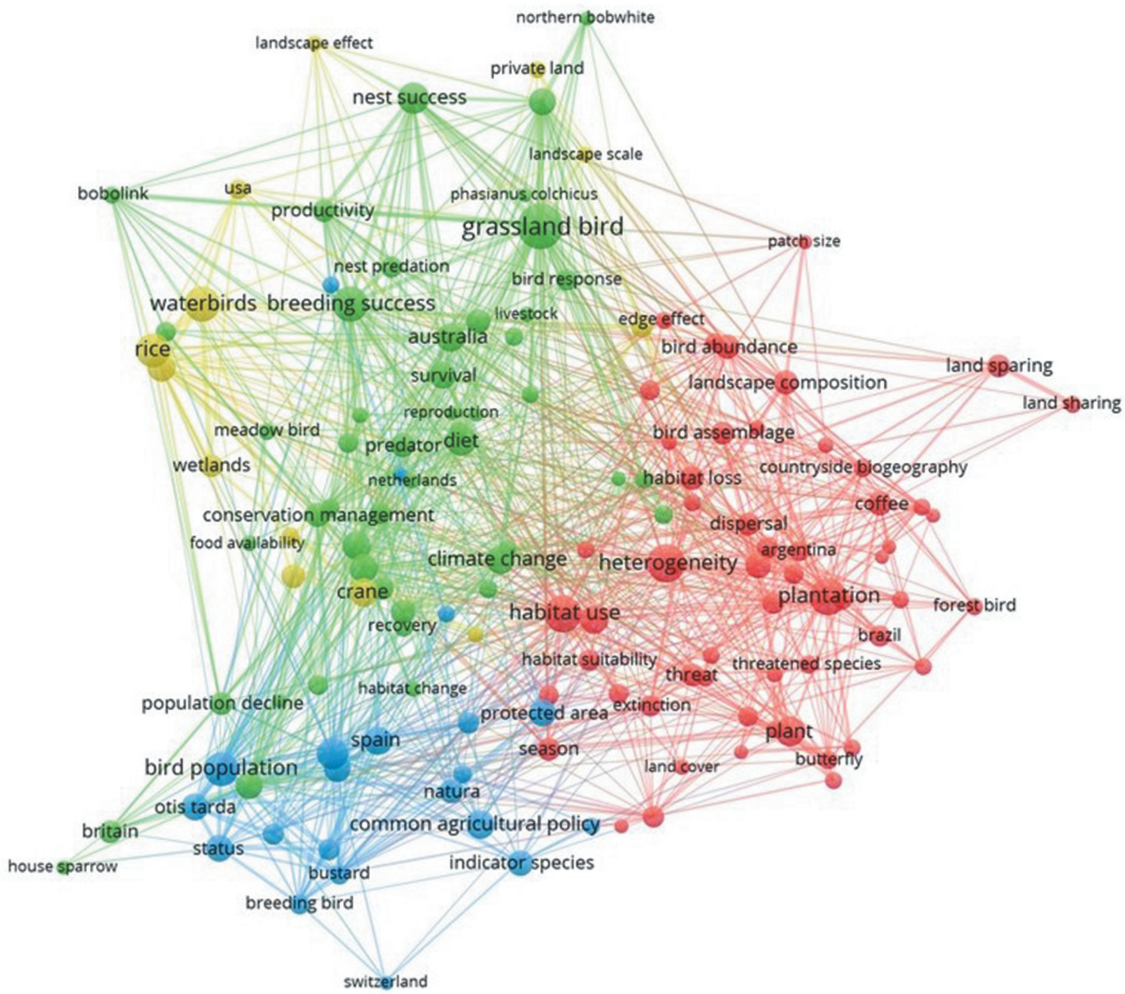

Figure 5. Network map created by VOSviewer based on co-occurrence of terms (topics) in the article title and keywords. The size of the circles is proportional to the number of papers. The different colours illustrate the different clusters in which the terms (topics) are grouped. Only terms with the top 60% relevance scores (139 terms) are plotted.

Table I. Coefficients (Coef.) and confidence intervals (CI lower limits; upper limits) of the explanatory variables including in the best candidate models (ΔAIC < 2) explaining the number of papers on farmland birds.

	Model-1		Model-2		Model-3	
Predictor	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI
Intercept	−3.24	−3.79; −2.7	−2.87	−3.85; −1.89	−3.28	−3.89; −2.66
Log-papers-Scopus/1million	0.68	0.55; 0.8	0.6	0.39; 0.81	0.68	0.55: 0.81
Log-Bird Species/km^2	0.32	0.14; 0.49	0.31	0.14; 0.49	0.32	0.14; 0.49
Agriculture GDP (%)	–	–	−0.01	−0.03; 0.01	–	–
Agricultural land (%)	–	–	–	–	0.001	−0.005; 0.01

Eastern Europe (Ukraine and Serbia) had the lowest residuals value (fewer papers than expected), whereas some countries of Latin America (Costa Rica, Nicaragua, and Panama), Australia, Canada, and Sweden had the highest values (more papers than expected) (Fig. S4 and Figure 6).

Discussion

Drivers of differentiated publication effort among countries

Our results revealed persistent interest in the research of farmland birds and their conservation, which is

Table II. Model selection according to the AIC criteria and model averaging results for candidate models (ΔAIC < 2) explaining the number of papers on farmland birds. The coefficients for each variable in each model are shown.

Predictor	Model-1	Model-2	Model-3	β	SD
Log-papers-Scopus/1million	0.349	0.174	0.33	0.219	0.115
Log-Bird Species/km^2	0.164	0.090	0.063	0.106	0.053
Agriculture GDP (%)	0	−0.003	0	−0.001	0.002
Agricultural land (%)	0	0	0.001	0	0.0001
AIC	148.78	149.92	150.71		
ΔAIC	0	1,14	1,93		
ωm	0.514	0.291	0.196		

β = averaged parameter estimate; SD = standard deviation; ωm = Akaike model weight.

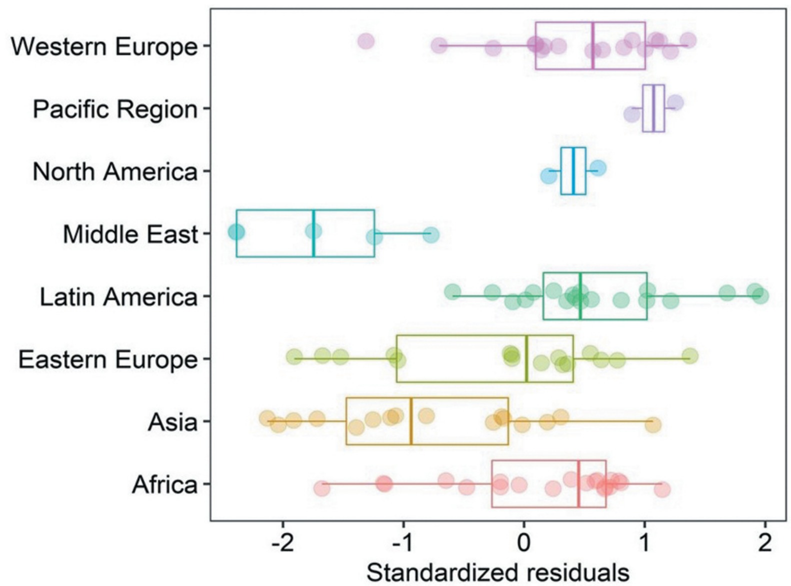

Figure 6. Standardized residuals from the model predicting the number of papers on farmland birds per 1 million inhabitants based on the variables log-papers in Scopus/1 million inhabitants, log-bird Species/km^2, agriculture added value (% GPD), and the agricultural area (%) grouped by geographical regions.

widespread globally and still growing (Figure 1). We also showed an important spatial bias in the scientific literature concerning this topic. More papers concentrated in Western Europe and North America, and fewer papers were affiliated to authors from Africa, Asia, and the Middle East. Even within Europe, more studies have been published by Western than Eastern European researchers. Bias in research and sampling efforts between countries and regions has been previously identified by some works in the field of biodiversity conservation (e.g., Wilson et al. 2016; Di Marco et al. 2017; Christie et al. 2020), but we showed here the analysis of bias performed globally and specific to farmland birds. Biased identification of conservation problems limits the effectiveness of conservation actions in less studied regions and in general obfuscates our view of the wildlife problems (Trimble & van Aarde 2012; Hughes et al. 2021).

Our results showed that the research efficiency of a country was mainly explained by Gross Domestic Product per cápita and the percentage of GDP invest on Research and Development (R & D). The long-standing democratic past of the countries affected the translation of economic wealth into scientific production (Allik et al. 2020). Indeed, the most important predictor of the number of papers on FBC was the general country's scientific production in Scopus, which reflects the scientific capacity of a country. The financial constraint may be an essential factor reducing the scientific capacity of low GDP countries. This in turn may translate into insufficient conservation effort there. Importantly, tropical countries harbouring greater biodiversity, are often less studied than temperate countries from northern latitudes, which may be partly explained by economic factors (Wilson et al.

2016; Vinkler 2018; Allik et al. 2020; Guerrero-Casado & Monge-Nájera 2021).

The low scientific effort put on the topic of bird or farmland conservation limits evidence-based solutions and may prevent practical implementation even if funds appear. The additional risk is associated with the misuse of available funds. The tendency, common in Europe, to move public support toward market-driven, applied research may have negative consequences for basic research, including conservation science and biodiversity (Santamaría et al. 2013). For example, in Poland and other central European countries over the last two decades, considerable funds have been dedicated to environmental research connected with the wind energy industry, mostly conducted in agricultural areas. However, these funds did not translate into the number of publications in top scientific journals, but rather deteriorated the quality of studies, hampered the innovations and exchange of knowledge and even could cause long-term damages to natural resources (Wuczyński & Tryjanowski 2013).

As we expected, the variables related to the importance of agriculture and avian diversity were less important in models explaining scientific effort on the FBC of a country. There are countries where agriculture is a vital source of national income (percentage of GDP) such as Turkey, China, some South American countries, and North Africa (Morocco, Algeria, Egypt) but they still have a low scientific production on FBC (Figure 3c). We identified countries whose low scientific production is not explained by the selected explanatory variables and countries with unexpectedly high research effort on FBC in relation to the importance of agriculture (Fig. 8 and S1). This fact has important conservation implications: the scientific knowledge on farmland birds is often poor in countries with large agricultural areas and high bird species richness, raising the urgent need for intensified research in these countries. In absolute terms, there are more threatened bird species in human-changed environments in Asia, Africa, and South America than in Europe and North America (Wright et al. 2012). Thus it is a paradox that the more threatened bird species, the fewer scientific publications. Developing countries could apply the European "seminatural habitats paradigm" to protect valuable farmland habitats (Wright et al. 2012). Europe is a particular example of a region where a long tradition of farmland bird studies exists and a long-term conservation effort has been introduced (e.g., Young et al. 2005). European Environment Agency has delimited "high nature value farmlands" to recognize those agricultural areas associated with either a high species and habitat diversity or the presence of species of European conservation concern or both (Morelli 2018). Moreover, agriculture is a important activity in the areas included in the Natura 2000 network (Tsiafouli et al. 2013).

Spatial patterns in scientific collaboration

We found significant spatial biases in scientific collaboration among countries (Figure 4). Naturally, countries located close to each other and having high scientific capacity tended to cooperate frequently, e.g., within Western Europe. However, cooperation between the western and eastern parts of Europe was not as tight as it could be expected from geography. This bias may cause difficulties in the proper implementation of large-scale actions such as nature conservation within the Common Agricultural Policy (CAP). For example, it is commonly agreed that increasing landscape-scale habitat heterogeneity is beneficial for biodiversity in farming systems (Fahring et al. 2015). However, this approach could have the opposite effect in low-intensity landscapes, such as semi-natural steppe-like pastures, hosting specialist species of high conservation priority. On this basis, Batáry et al. (2011) suggested that caution is necessary against the uncritical application of measures to increase habitat heterogeneity in low-intensity agricultural landscapes.

Scientific collaboration is also essential between countries hosting the same bird populations over various phases of the annual cycle (breeding, stopover, and wintering). There are several examples of such collaboration between South American countries and the USA or between some Asian countries and Australia (Figure 4). In contrast, Europe having the largest number of papers on farmland birds showed relatively low collaboration with the Middle East and African countries (Figure 4). This is particularly relevant in the case of migratory birds as some reviews (Wilson et al. 2016; Di Marco et al. 2017; Christie et al. 2020) of the global distribution of publications in the field of biodiversity conservation revealed a low number of scientific evidence from important stopover and wintering areas for migratory birds, i.e., Middle East, Africa, Central America or Oceania. This, in turn, indicates a great need for evidence of the effects of changes in agriculture in such areas. Stopover sites play a vital role for birds to accumulate energy and physiologically recover during migration (Schmaljohann et al. 2022), and agricultural land serves such sites (Blount et al. 2021). Therefore, the solution for this problem is undertaking join research by scientists from different countries, particularly the collaboration between countries that differ in importance for birds over their year cycle and that have different experience in FBC.

Associations among topics

Analysis by VOSviewer identified some interesting relationships between topics and their associations. General topics and issues such as land-use change, habitat structure, and climate change were predominant and central in the association chart, while specific topics, e.g., organic farming, toxicology, or tillage were less abundant (Figure 6). Considering organic farming, it is probably due to the fact that this topic is region-specific and not widely represented. Nevertheless it has been shown that this agricultural practice has a very positive effect on farmland birds (e.g., Bengtsson et al. 2005; Doxa et al. 2010; Smith et al. 2010). The terms linked to population decline and trends were associated with European countries and some of the most common European farmland bird species, probably due to long-term population monitoring programs implemented in Europe, i.e. PanEuropean Common Bird Monitoring Scheme (e.g. Rigal et al. 2023). It is also worth mentioning that due to the extensive use of insecticides and fertilizers in Europe and North America, leading to reduced food availability (Blüthgen et al. 2022; Neff et al. 2022; Mancini et al. 2023) and decreased breeding success, many bird populations have visibly declined over the last decades (Newton 2004; Hallmann et al. 2014; Stanton et al. 2018). This result again underlines the need for long-term population monitoring in other parts of the world, especially in developing countries. Furthermore, terms such as species richness, functional diversity, or conservation value were strongly associated with heterogeneity (Figure 5). It is also remarkable that studies from the tropics mostly focus on forest birds and the relationship between bird diversity and the deforestation (aimed at establishing new arable crop areas) (e.g., Neate-Clegg & Şekercioğlu 2020). Indeed, when the paper's screening was performed, many papers were discarded because farmland, agriculture, or crops were only mentioned as one of the main causes of habitat loss. It is also worth noticing that, in some developing countries in the tropics (e.g., sub-Saharan countries) agriculture is often characterized by subsistence farming at a small-scale (Gallup & Sachs 2000; Tscharntke et al. 2012). Therefore, much of the current African farmland conforms to a land-sharing approach (Marcacci et al. 2020). Still, the lack of studies in different environments prevents assessing the importance of agricultural landscapes for birds. As we showed, many tropical countries had few articles on FBC despite their large area devoted to agriculture and a high bird species richness. Therefore, in tropical environments, research efforts should also be focused on agricultural landscapes to assess the plausible conservation value of the agroecosystems.

Conclusions

We have evidenced that the scientific production on FBC is spatially uneven on global and regional scales, indicating countries and regions with a large agriculture area and high avian diversity but insufficient scientific evidence. Therefore, in the recent times of globalisation, the intensity of research is still determined by the wealth of countries, regardless of the conservation relevance. This paradox can have ecological consequences, since the importance of agricultural landscapes for bird conservation may be undervalued in many parts of the world. Therefore, research should be intensified in these regions. To achieve this goal, scientific collaboration between high-income countries with greater experience in farmland ecology and countries with lower achievements in this area seems to be essential.

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Authors' contribution

Conceptualization: JGC, MT, ZMR; Data collection: JGC, MT; Statistical analysis: JGC, MT, LD; Writing the original draft: JGC; writing—review and editing: MT, ZMR, LD, PS, AW. Supervision: PS, AW.

Supplementary material

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