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Alarming conservation status of Western European steppe birds and their habitats: An expert-based review of current threats, traits and knowledge gaps[☆]

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ABSTRACT

European steppe birds are facing unprecedented declines, positioning among the most threatened bird groups. We provide a comprehensive review and synthesis of the available knowledge on Western European (WE) steppe birds, focusing on their ecology, functional traits, population range trends and major threats. Using an expert-based participatory approach, we first created a consensual list of 37 WE species and reviewed the current knowledge on these key topics. Although 67.6 % of species show declining population ranges, only 18.9 % are classified as Endangered or Vulnerable according to the European IUCN Red List. Notably, several species exhibit range contractions over 5 % yet remain listed as Least Concern, indicating a need for re-evaluation based on the most up-to-date data. Threatened species have distinct functional traits compared to non-threatened species, typically being sedentary, large-bodied, long-lived, and exhibiting ground-foraging and ground-nesting behaviours. This highlights the potential for functional diversity loss if threatened species become extinct. Species experiencing the greatest range contractions share many of these traits or exhibit arboreal or aerial lifestyles, carnivorous diets and partial to fully migratory behaviours. Experts identified land use change and human-caused mortality as the main threats, followed by pollution and climate change, although the effects of the latter remain poorly understood for most species. Because significant knowledge gaps on climate and pollution effects remain for most species, these two threats should be the focus of future investigations. This synthesis enhances our understanding of the threats faced by WE steppe birds and provides guidance for prioritizing future research and conservation efforts.

1. Introduction

Global change is driving biodiversity loss through an unprecedented decline in populations, species, and habitats at both local and global scales (Brondízio et al., 2019). Early conservation efforts (prior to the 1970s) primarily focused on the strict protection of pristine sites by restricting or excluding human activities, and the implementation of ex situ programs for highly threatened, charismatic/flagship species (Mace, 2014). Yet, it is increasingly recognized that ‘conservation without people’ strategies are effective in the short term (Elsen et al., 2020), and that their long-term success is seldom achieved. Human activities outside protected areas, detrimental illegal activities within them, and the interconnectedness of ecological processes between protected and non-protected regions undermine this strategy (Ament and Cumming, 2016; Elsen et al., 2020; Semper-Pascual et al., 2023). Additionally, this approach is ineffective for conserving human-made habitats (e.g., Gameiro et al., 2020; Palacín and Alonso, 2018), which rely on the long-term maintenance of specific land uses (Kremen, 2015; Phalan et al., 2011). As a result, modern conservation strategies are shifting towards ‘conservation for people’ and/or ‘conservation with people’ approaches (Díaz, 2023; Mace, 2014), aiming to integrate human activities with biodiversity conservation within socio-ecological systems (Bennett et al., 2015; CBD, 2022). These approaches require a comprehensive and multidisciplinary understanding of how land use and other drivers of global change impact population and genetic diversity, as well as the trade-offs and synergies between biodiversity conservation and other relevant societal goals (Díaz et al., 2015).

Steppes are a prime example of socio-ecological systems, consisting of natural and semi-natural open habitats, including natural steppes, dry cereal farmlands, grasslands, and shrublands (Sainz Ollero, 2013). These ecosystems are relatively flat and treeless with sparse vegetation dominated by herbaceous plants or dwarf shrubs (Bond, 2019; Kürschner and Parolly, 2012; Sainz Ollero and van Staalduinen, 2012; Sümegi, 2005). Natural steppes typically arise from altitudinal, climatic, and edaphic tree-limiting conditions, while human-shaped steppes result from the interplay of these factors with traditional low-intensity human activities such as crop rotational systems, extensive grazing, wood harvesting and controlled burns to renew pastures (Henry et al., 2010; Miller, 2005; Suárez et al., 1992; Ventresca Miller et al., 2020). However, both types of steppes are influenced by human activity to some extent, highlighting the need to integrate conservation with sustainable land use (Halada et al., 2011; Pérez-Granados et al., 2025). While steppes and their wildlife have co-evolved alongside human activities for millennia (Blondel, 2006), rapid recent changes threaten these ecosystems and the species they sustain.

Extrazonal European steppes, isolated from their Asian counterparts for millennia, form stable refugia and harbor unique endemic species (Kirschner et al., 2020). Hence, preservation of European steppes is not only key to conserving their intrinsic biodiversity but also critical for maintaining the genetic and ecological integrity of the entire Eurasian steppe biome (Kirschner et al., 2020). Specifically, European steppes are

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[1] Equally contributed.

vital for bird conservation, since 55 % of European bird species on the IUCN Red List are highly dependent on these habitats (Burfield et al., 2023; Burfield and Van Bommel, 2004). However, the definition of steppe birds is controversial, resulting in multiple, non-consensual species lists (see e.g., Santos and Suárez, 2005; Suárez et al., 1997). This controversy stems from the differences in species' reliance on these habitats throughout the annual cycle, which partly explains the heterogeneity of life-history and functional traits across species inhabiting steppe habitats.

Functional traits provide a critical framework for understanding the diversity of forms and functions across organisms (de Bello et al., 2021; Mammola et al., 2021). Because functional traits shape species' biology and interactions with the environment, they are increasingly used to assess impacts of global change drivers on biodiversity (Guerrero et al., 2024; Romero-Muñoz et al., 2021; Soares et al., 2022), and to prioritize species, habitats, and ecosystems for conservation (Brum et al., 2017; Pollock et al., 2017). Well-established trade-offs among traits constrain organisms' forms and functions along few independent trait dimensions, thus limiting possible trait combinations within two – or highly dimensional spaces, also called functional trait spaces (Carmona et al., 2021; Díaz et al., 2016; Mouillot et al., 2021). Despite their potential, the functional diversity of steppe birds remains poorly explored (but see Guerrero et al., 2024). Investigating the functional space of steppe bird species and its relationship with their threat status is therefore vital for understanding the implications of species loss for functional diversity in these ecosystems.

This study aims to review, update and synthesize the available ecological knowledge on Western European steppe birds to provide a solid scientific basis for a better design of conservation strategies. Using an expert-based participatory approach, we first developed a comprehensive and consensual list of Western European steppe bird species. The expert panel subsequently reviewed the current knowledge on the ecology, species traits, population trends and main threats for all species included in the list. The specific objectives of this work were to: 1) establish an agreed-upon list of Western European steppe bird species; 2) collect and synthesize knowledge of their population sizes, range trends and conservation status; 3) examine the differences in the functional space occupied by threatened and non-threatened species, and analyze the relationships between range trends and species' functional traits; 4) assess the current situation of Western European steppe birds concerning the main drivers of biodiversity loss and provide an overview of the main literature on these drivers; and 5) identify key knowledge gaps for future research. The results of this work will be useful to guide research efforts targeting the identified knowledge gaps and to highlight the threats faced by Western European steppe birds, facilitating an evidence-informed design of subsequent conservation actions.

2. Methods

To review and synthesize knowledge on steppe birds, we formed a panel of 63 active experts in different aspects of steppe ecology and steppe bird conservation across Europe (Appendix A). Two European countries, Spain and Portugal, accounted for 50 out of the 63 (79.4 %) participants. This geographical bias aligns with the current distribution of steppe birds in Western Europe, with the main populations currently found in Spain and Portugal (Traba and Morales, 2019). In this study, Western European steppe birds (hereafter referred to as *steppe birds*) refer to species found across Europe, including the Canary Islands, but excluding those that are restricted to eastern regions of Europe such as western Russia, Kazakhstan, Transcaucasia, Turkey, and Cyprus (see criteria for defining steppe birds in Section 2.1).

The expert panel's workflow comprised three phases. In the first phase (February 2023), the panel convened in person to define and approve the criteria for identifying steppe bird species and to provide a comprehensive list of these species (see Section 2.1 below). In the second phase (June 2023), members of the expert panel received a link to a Google Docs document and were explicitly asked to summarize the current situation of steppe birds and main threats. Finally, in the third phase (September 2024) we asked the panel members to rank threats for each species based on their scope, severity and the available knowledge (more information in Sections 2.4 and 2.5, respectively).

2.1. Western European steppe bird species

The expert panel established a set of criteria to determine the key characteristics that define steppe birds and identify the species that qualify. The process began with the 26 species identified by Suárez et al. (1997), which included steppe birds breeding in the Iberian Peninsula and the Balearic Islands. These species were selected based on four criteria: 1) species typical of, or very frequent in the Mediterranean region, 2) ground-nesting species, 3) species exclusive to treeless, mainly flat areas; and 4) species whose main European populations are found in Spain and Portugal. This list was employed as it is widely recognized within the scientific community as a comprehensive and reliable foundation for identifying steppe bird species in the region (see for example Morales and Traba, 2016; Santos and Suárez, 2005).

This list was refined by selecting those species that simultaneously met the following expert-approved criteria: 1) core populations occur in extensive dry farmlands, grassland or open shrubland environments in treeless, predominantly flat zones, 2) ground-nesting in open habitats, 3) dependence on flat, open steppe-like environments for feeding; 4) terrestrial lifestyle and ground-foraging behaviour; and 5) ethological, physiological or ecological adaptations to arid or low primary productivity areas. We included five species that are not ground-nesters (lesser kestrel *Falco naumanni*, European roller *Coracias garrulus*, Iberian grey shrike *Lanius meridionalis*, lesser grey shrike *Lanius minor*, and little owl *Athene noctua*) but are strongly associated with steppe habitats (Bustamante, 1997; Campos et al., 2011; Catry et al., 2017; Giralt et al., 2008; Michel et al., 2017; Šálek et al., 2016). Likewise, we also included five other species that are not typically classified as steppe species in other regions, but are associated with steppe ecosystems in Western Europe for at least part of the annual cycle (Eurasian skylark *Alauda arvensis*, northern lapwing *Vanellus vanellus*, European golden plover *Pluvialis apricaria*, pallid harrier *Circus macrourus* and merlin *Falco columbarius*; Gillings et al., 2007; Graham, 2006; Limiñana et al., 2015; Suárez et al., 2003). The African houbara *Chlamydotis undulata*, the Berthelot's pipit *Anthus berthelotii* and the Canary Islands stonechat *Saxicola dacotiae*, were also included in the list, since they met several of the criteria (Carrascal et al., 2008; Garcia-del-Rey and Cresswell, 2007; Illera, 2001). In contrast, the black wheatear *Oenanthe leucura* and the trumpeter finch *Bucanetes githagineus*, considered as steppe birds by Suárez et al. (1997), were excluded. While both species are associated with semi-arid habitats, they are linked to ravines, dry riverbeds, and other rocky environments, including river or coastal cliffs (Manrique-Rodríguez et al., 2003). Consequently, they are not considered steppe specialists, as their habitat preferences and associated threats may not accurately reflect the broader ecological and conservation challenges faced by the majority of traditionally recognized steppe birds (e.g., bustards, sandgrouse and larks). The final list of steppe bird species consisted of 37 species (Box 1).

2.2. Conservation status, population sizes and range trends

For each steppe bird species, we collected information on population size, range trends and conservation status from: i) the second European Breeding Bird Atlas (EBBA2), conducted by the European Bird Census Council (EBCC, 2022), and ii) the IUCN Red List at European level (IUCN, 2024a). We did not consider data from the Pan-European Common Bird Monitoring Scheme (PECBMS) since population trends were not available for most species. While the present study focuses on Western European steppe birds, information on population size, range trends and conservation status are provided at the broader European

Box 1

List of WE steppe bird species, compiled based on the criteria outlined in the Methods section. The table includes the change index, which quantifies the magnitude of change in square occupancy between EBBA1 and EBBA2, and the conservation status (threat categories) according to the IUCN Red List at European level. Detailed data regarding population size of each species are provided in Appendix D.

Family	Species	Change index	IUCN status
Accipitridae	Hen harrier *Circus cyaneus*	−17.0	Least Concern
	Montagu's harrier *Circus pygargus*	6.4	Least Concern
	Pallid harrier *Circus macrourus*	0.1	Least Concern
Alaudidae	Calandra lark *Melanocorypha calandra*	−8.5	Least Concern
	Crested lark *Galerida cristata*	−11.6	Least Concern
	Dupont's lark *Chersophilus duponti*	−1.6	Vulnerable
	Eurasian skylark *Alauda arvensis*	−2.7	Least Concern
	Lesser short-toed lark *Alaudala rufescens*	−20.9	
	Short-toed lark *Calandrella brachydactyla*	−10.5	Least Concern
	Thekla lark *Galerida theklae*	4.5	Least Concern
Burhinidae	Stone curlew *Burhinus oedicnemus*	−2.3	Least Concern
Charadriidae	European golden plover *Pluvialis apricaria*	−3.1	Least Concern
	Northern lapwing *Vanellus vanellus*	−1.6	Vulnerable
Cisticolidae	Zitting cisticola *Cisticola juncidis*	10.9	Least Concern
Coraciidae	European roller *Coracias garrulus*	−20.2	Least Concern
Emberizidae	Corn bunting *Emberiza calandra*	0.1	Least Concern
Falconidae	Lesser kestrel *Falco naumanni*	−14.3	Least Concern
	Merlin *Falco columbarius*	−5.0	Vulnerable
Glareolidae	Cream-coloured courser *Cursorius cursor*		Near Threatened
	Collared pratincole *Glareola pratincola*	−4.6	Least Concern
Laniidae	Iberian grey shrike *Lanius meridionalis*	−4.4	Vulnerable
	Lesser grey shrike *Lanius minor*	−10.7	Least Concern
Motacillidae	Berthelot's pipit *Anthus berthelotii*		Least Concern
	Tawny pipit *Anthus campestris*	−4.5	Least Concern
Muscicapidae	Black-eared wheatear *Oenanthe hispanica*	−10.8	Least Concern
	Canary Islands stonechat *Saxicola dacotiae*		Near Threatened
	Northern wheatear *Oenanthe oenanthe*	−3.0	Least Concern
Otididae	African houbara *Chlamydotis undulata*		Vulnerable
	Great bustard *Otis tarda*	−23.3	Least Concern
	Little bustard *Tetrax tetrax*	−14.9	Vulnerable
Phasianidae	Common quail *Coturnix coturnix*	8.6	Near Threatened
	Red-legged partridge *Alectoris rufa*	5.7	Near Threatened
Pteroclidae	Black-bellied sandgrouse *Pterocles orientalis*	−5.4	Endangered
	Pin-tailed sandgrouse *Pterocles alchata*	−24.6	Least Concerned
Strigidae	Little owl *Athene noctua*	−3.8	Least Concern
	Short-eared owl *Asio flammeus*	−1.8	Least Concern
Sylviidae	Spectacled warbler *Sylvia conspicillata*	4.5	Least Concern

scale. This includes data from the western regions of Russia and Kazakhstan, Transcaucasia, Turkey and Cyprus, as well as nearby archipelagos in the Atlantic, Arctic, and the Mediterranean Sea (see Appendix B). We use data at this scale because it represents the most recent and standardized information currently available.

Using data from EBBA2, we compiled the number and percentage of 50-km squares where each species occurred, along with a change index that quantifies shifts in the number of occupied squares between the first European Breeding Bird Atlas (EBBA1, monitoring period between 1972 and 1995) and EBBA2 (monitoring period between 2013 and 2017). For a detailed description of the methodology used to estimate this change index and other aspects of EBBAs, see Keller et al. (2020).

Additionally, we included the population trend classification (i.e. Loss, Stable, Gain, Uncertain trend) and the associated level of certainty in this classification provided by EBBA2. Information on European population size (defined as the number of mature individuals) was obtained from the IUCN Red List at European level. Conservation status (threat category) and population size trends in Europe were obtained from the IUCN Red List. We did not consider more recent estimates of population sizes and trends because they were available for a handful of species only (e.g., great bustard - Alonso and Palacín, 2022 - African houbara - Alonso et al., 2020a; Carrascal, 2022; Ucero et al., 2021 - Canary Islands stonechat - Illera et al., 2024, among others; see Appendix D for more information).

2.3. Functional traits

We compiled trait data from our own measurements derived from multiple research projects over the past decades and from the primary scientific literature, including databases, books, and scientific papers. Based on literature and expert knowledge, we collected information on traits related to morphology, life history, distribution and abundance, behaviour, foraging and nesting habitats, diet, and migration. Additionally, we derived relative brain size as the residual of the log-log relationship between brain size and body mass (Sol et al., 2007) and retrieved this trait for further analyses (traits are listed in Appendix C).

We described the functional space occupied by threatened and non-threatened steppe bird species (see Section 2.2 Conservation status, population sizes and range trends), and calculated their functional richness (FRic), i.e. the proportion of the functional space occupied by threatened and non-threatened species relative to the entire assemblage (Villéger et al., 2008). Before undertaking the functional diversity (FD) analyses, we checked the distribution of variables, identified missing data, and assessed the collinearity among continuous traits using a Pearson's correlation test (Palacio et al., 2021). We discarded redundant traits ($r > 0.5$) or those representing similar functions and forms in the functional space (e.g., degree of development – precocial vs. altricial – was discarded over a development continuum index, trophic level was discarded over trophic niche, see definitions in Appendix C). We imputed missing values for traits with incomplete data with the R package "missForest" (Stekhoven and Bühlmann, 2012). Imputed traits were birth or hatching weight (17 missing values), absolute brain size (15), habitat breadth (2), eye axial length (20), eye transverse diameter (25), and population density (1). To homogenize the distribution of variables, we log-transformed all continuous variables without negative values. We also standardized all continuous traits to mean = 0 and standard deviation = 1 to ensure comparable ranges among traits.

Next, we built a *species* * *trait* matrix, and a *threatened/non-threatened* * *species* matrix, with the latter representing the presence/absence of each species in each category (i.e., threatened or non-threatened steppe bird species according to their European IUCN status; Appendix D). Because our trait matrix contains both continuous and categorical variables, we used the Gower distance to estimate trait dissimilarity among species (Gower, 1971; Laliberté and Legendre, 2010). We weighed traits equally and applied a principal coordinate analysis (PCoA) ordination based on the distance matrix to build a multidimensional functional space.

We visualized the trait space as the first two axes of the PCoA using the trait dissimilarity matrix as input data, using the R package 'ape' (Paradis and Schliep, 2019). To relate traits to the ordination axes, we used the function *envfit* from the R package 'vegan' (Oksanen, 2009). This function calculates a multiple linear regression of the traits (dependent variable) and species scores on ordination axes (independent variables). The normalized regression coefficients multiplied by the square root of the coefficient of determination are used to position the trait onto the ordination diagram. Subsequently, we estimated the density of species on the ordination diagram using a kernel density function. Lastly, we calculated FRic (functional richness) for threatened and non-threatened species. Because FRic is highly influenced by species richness (i.e., a higher number of species can lead to a broader range of traits), we calculated the Standardized effect size of FRic (SESFRic) as (mean observed FRic - mean expected FRic)/(SD of expected FRic). Expected values of FRic were generated based on 999 permutations of the community matrix using the "independent swap" null model, which randomizes the data matrix and maintains the original species richness. We performed all FD analyses in the R package "mFD" (Magneville et al., 2022) and used the function randomizeMatrix from the R package "picante" (Kembel et al., 2010) to generate the null models.

We analyzed relationships between range trends and species' positions within the trait space defined by the first two axes of the PCoA using phylogenetic generalized least squares (PGLS) regressions to account for potential non-independence due to shared evolutionary history (Freckleton et al., 2002). We estimated the phylogenetic scaling parameter lambda (λ), which ranges from 0 (indicating phylogenetic independence) to 1 (indicating complete phylogenetic trait conservatism or dependence; Freckleton et al., 2002) and derived phylogenetically corrected model estimates. A consensus phylogeny for the studied species was constructed using Mesquite software (Maddison and Maddison, 2011). We used the consensus tree based on 100 Ericson trees extracted from the phylogeny published by (Jetz et al., 2012) (birdtree.org). We conducted the analyses using the R packages "ape" (Paradis and Schliep, 2019), "MASS" (Venables and Ripley, 2002), and "mvtnorm" (Genz et al., 2021), and the function *pglm3.3.r*. All analyses were performed in R (R Core Team, 2024).

2.4. Overview of main threats to steppe birds

The expert panel evaluated the current status of steppe birds in relation to the main drivers of biodiversity loss. Participants were provided with a Google Docs link and explicitly asked to summarize the current situation of steppe birds in relation to the first eight targets of the Kunming-Montreal Global Biodiversity Framework (KM-GBF, CBD, 2022). We used the first eight KM-GBF targets because they aim to halt biodiversity loss by addressing its main drivers, including land use change, overexploitation, invasive species, climate change, and pollution (see Pérez-Granados et al., 2025 for more details). These targets include i) protecting, managing, restoring, and connecting at least 30 % of key areas (Targets 1, 2, and 3), ii) ensuring management actions to reduce extinction risk for threatened species and promoting sustainable use of species and ecosystems (Targets 4 and 5), iii) preventing or reducing the introduction and establishment of invasive alien species (Target 6), iv) reducing nutrient loss to the environment and the use of pesticides (Target 7), and v) contributing to climate change mitigation and adaptation (Target 8; CBD, 2022). During the process, experts iteratively shared their input, proposing new arguments or editing the existing ones based on direct and ongoing feedback from fellow participants and the team who facilitated the process. The responses were compiled and synthesized by a core team leading the writing of the manuscript (Appendix A).

2.5. Species-specific threats and knowledge gaps

The expert panel also ranked the identified threats for each species based on their expert criteria (see Appendix E for detailed instructions and the table provided to the experts). For simplicity, the identified threats were classified into six main groups, related to the eight KM-GBF targets: 1) *land use change* (e.g., agriculture, afforestation, urbanization, infrastructure development); 2) *human-induced mortality* (e.g., non-natural mortality caused by agricultural practices such as ploughing and mowing, collisions and electrocutions with human infrastructures, or increased predation due to land use changes or other human activities, among others); 3) *unsustainable exploitation* (e.g., hunting or poaching); 4) *pollution* (e.g., noise or light pollution, agrochemical use in agriculture); 5) *invasive species* (i.e., introduction of non-native birds, plants, etc.); and 6) *climate change* (e.g., shifts in the distribution of suitable environmental conditions).

Following the IUCN criteria (IUCN, 2024b), experts were instructed to classify each threat according to its *scope* (i.e., the proportion of the total population affected: high > 90 %, medium 50–90 %, low < 50 %, or unknown) and *severity* (i.e., the impact on population trends over 10 years or three generations, whichever is longer: high > 20 % decline, medium < 20 % decline, low or negligible decline, or unknown). Additionally, participants were asked to indicate whether they had direct experience with the species-threat interaction and to rate their confidence in the classification based on their *level of knowledge*: i) High, if they had extensive knowledge on the subject (e.g., >5 articles available); ii) Medium, for moderate knowledge (2–5 articles); and iii) Low, for limited knowledge (<2 articles). Threats were specifically evaluated for species in steppe environments, as the main threats to species in other habitats (e.g., during migration or in other habitat types for more generalist species) may differ or present distinct challenges. The information from these tables was summarized to rank the threats to European steppe birds and to assess the current knowledge on these threats, with the aim of identifying key knowledge gaps.

3. Results and discussion

3.1. Conservation status, population sizes and range trends

Overall, European steppe bird populations are declining. Data from the EBBA2 show that 25 (67.6 %) of the 37 selected steppe bird species are experiencing range contractions. Additionally, population estimates for 7 (18.9 %) species are highly uncertain, and trends remain unknown

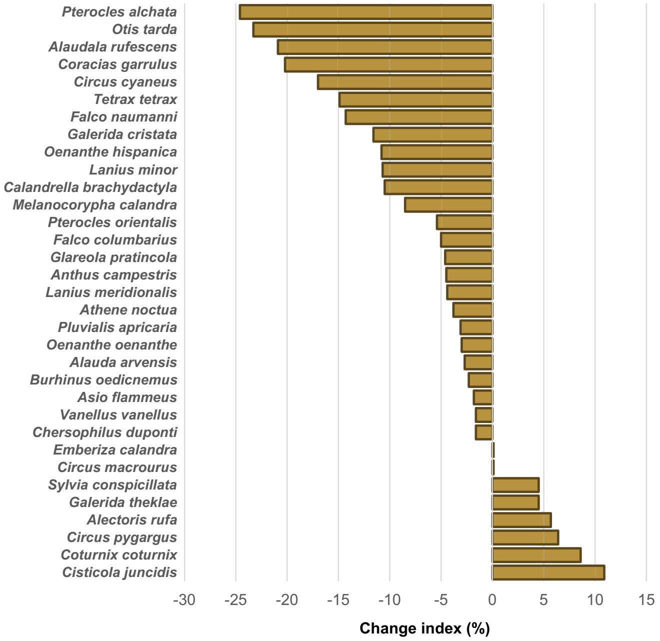

Fig. 1. Change index (%) in the number of occupied 50-km squares between EBBA1 (1972–1995) and EBBA2 (2013–2017) for Western European steppe birds. Berthelot's pipit *Anthus berthelotii*, African houbara *Chlamydotis undulata*, cream-coloured courser *Cursorius cursor* and Canary Islands stonechat *Saxicola dacotiae* are excluded due to unknown trends during the elaboration of EBBAs (see Box 1).

for 4 (10.8 %) species. The change index reflected an average loss of 5.8 % (±9.1 SD) 50-km occupied squares between EBBA1 (1972–1995) and EBBA2 (2013–2017), with values ranging from −24.6 to 10.9 (Box 1; Fig. 1). Small values reported are, however, biased by the large spatial scale (50 × 50 km) considered in the study. Species exhibiting the greatest range contraction (>20 %) include pin-tailed sandgrouse *Pterocles alchata*, great bustard *Otis tarda*, lesser short-toed lark *Alaudala rufescens* and European roller *Coracias garrulus*. In contrast, other species are expanding their ranges (>5 %), such as the common quail *Coturnix coturnix*, Montagu's harrier *Circus pygargus* and red-legged partridge *Alectoris rufa*. Meanwhile, species like corn bunting *Emberiza calandra* and pallid harrier *Circus macrourus* exhibit stable ranges (Box 1; Fig. 1).

It is important to note, however, that range trends do not always align with abundance trends. For example, while Montagu's harrier, red-legged partridge and common quail have increased their occupancy between the two EBBAs (Box 1; Fig. 1), these species have suffered sharp population declines in certain areas (Cabodevilla et al., 2021b; Gameiro et al., 2024; SEO BirdLife, 2019; Souchay et al., 2022). This apparent discrepancy may be influenced by improved monitoring techniques, larger survey efforts, or restocking practices, all of which contribute to the higher number of confirmed presences. Likewise, the range of trends described at the European scale, may differ from those found at national or regional scales.

While the population size of many species may still be considered large, others show strong negative population trends (e.g., little bustard *Tetrax tetrax* in Spain and Portugal: 50 % decline in 10 years, and France: 90 % decline in 20 years, Morales and Bretagnolle, 2022; Canary Islands stonechat: 63–70 % decline in 20 years, Illera et al., 2024; Dupont's lark *Chersophilus duponti*: 2.3 % average annual decline, Reverter et al., 2023; great bustard in Portugal, Spain and European Russia, with declines of 50 %, 28 % and 73 % respectively in the last 10–15 years, Alonso and Palacín, 2022; lesser kestrel in Spain: 6 % average annual decline; Aparicio et al., 2023; Bustamante et al., 2020). Some formerly widespread species are now threatened (e.g., black-bellied sandgrouse *Pterocles orientalis* – Mougeot et al., 2021, Mougeot et al., 2024, little bustard – Morales and Bretagnolle, 2022, both Endangered in Spain), and for others, information on population size and range trends remains limited or outdated (Appendix D). Finally, some species that were considered stable or increasing are now known to be declining and their situation is very critical (e.g., the African houbara - Alonso et al., 2024a - or the Canary Islands stonechat - Illera et al., 2024). This underscores the need for comprehensive and species-specific systematic monitoring to better understand population dynamics and inform conservation strategies.

Despite the declining status of most steppe bird species, only a small proportion are classified as threatened on the IUCN Red List at European level (Box 1; Appendix D). Specifically, 2.7 % are listed as Endangered (*n* = 1, black-bellied sandgrouse), 16.2 % as Vulnerable (*n* = 6, Dupont's lark, African houbara, little bustard, merlin, Iberian grey shrike and northern lapwing), 10.8 % as Near Threatened (*n* = 4, cream-coloured courser, red-legged partridge, common quail, and Canary Islands stonechat), and 70.3 % as Least Concern (*n* = 26). However, it is noteworthy that some species listed as Least Concern, such as the great bustard, the pin-tailed sandgrouse, and the European roller, have experienced range contractions in Europe, with declines between 20.2 % to 24.6 % (Box 1; Appendix D).

3.2. *Functional traits*

The first two dimensions of the functional space explained 73 % of the trait variation (Fig. 2A). PCoA1 explained 50 % of the variation and was linked to morphological traits such as wing size (length and Kipp's distance), body length, beak size (length, width, depth) and tarsus length, life history traits (maximum longevity, fledging age, incubation period and hatching weight), and habitat density (Fig. 2A). This dimension separated species with large body size, high longevity and high reproductive investment (slow pace of life) and a preference for open habitats (positive values), from small-sized, and fast-living species associated with semi-open habitats. Correspondingly, species belonging to the families Otididae, Burhinidae and Accipitridae were positioned towards positive values, whereas members of the families Sylviidae, Muscicapidae and Cisticolidae were positioned towards the negative end (Fig. 2B). PCoA2 explained 23 % of the trait variation, depicting a gradient from species with terrestrial lifestyle, ground foraging, ground nesting and sedentary behaviour, non-carnivorous diet, as well as small relative brain size (positive values) to species with aerial to insessorial

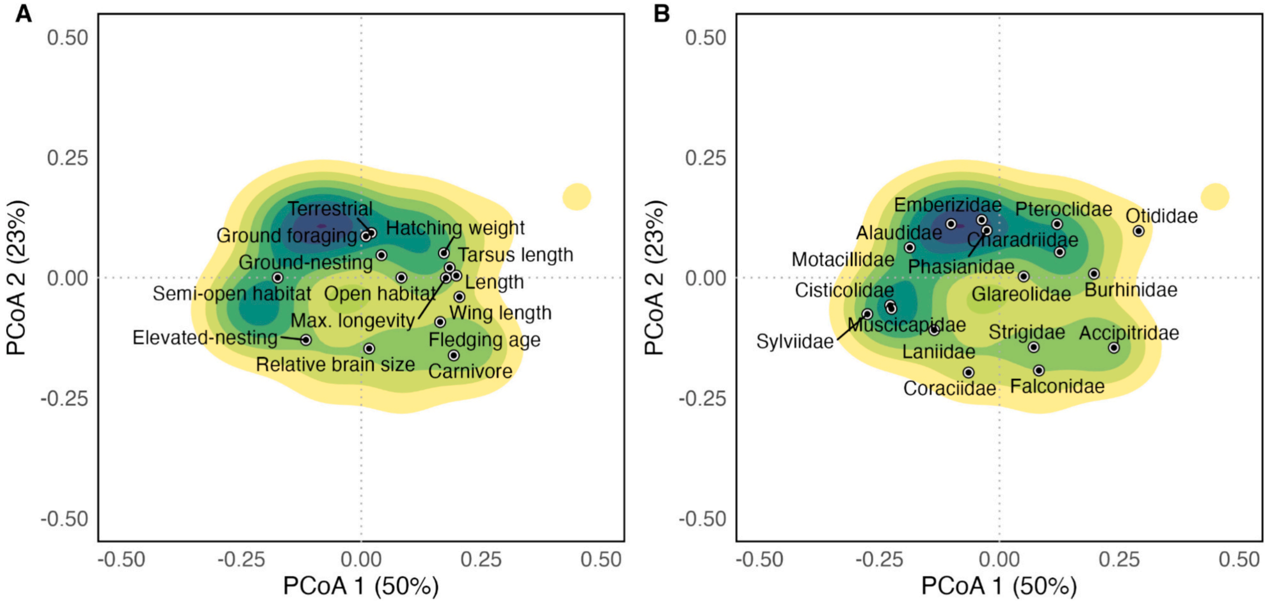

Fig. 2. Trait space representation for Western European steppe birds. (A) Distribution of steppe birds along the first two axes of a principal coordinate analysis describing the trait similarity among species. Colour gradients denote species density, with higher density in darker areas. The position of the most representative traits on each axis is mapped on the ordination diagram. (B) Same as (A) but mapping the position of each family onto the ordination diagram. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

lifestyles (aerial, arboreal and shrub foraging and nesting), with partial to full migratory behaviour, carnivorous diet, and large relative brain size (negative values) (Fig. 2A). Terrestrial species that typically nest and forage on the ground include those from the families Pteroclidae or Alaudidae (positive values in PCoA2, Fig. 2B), which in turn are separated along the PCoA1 axis due to their different pace of life.

Threatened steppe bird species ($n = 7$) had a smaller functional trait space than non-threatened ($n = 30$) species (SES.FRic = 0.46 vs 0.27, Fig. 3). The functional trait space of threatened steppe bird species was characterized by a major hotspot of large-sized, long-lived species (positive values of PCoA1), with ground foraging and ground nesting behaviours, as well as sedentariness (negative values of PCoA2). In contrast, non-threatened steppe bird species showed a larger functional trait space, with a moderate clustering of species with small body size and fast pace of life (Fig. 3). Hence, extinction risk in steppe birds is not randomly distributed across the functional trait space but predominantly affects large-sized, long-lived species (Fig. 3).

Range trends tended to be negatively related with PCoA1 ($B = -15.39 \pm 8.89$ SE, $t = -1.73$, $n = 33$, $p = 0.093$), and were quadratically related with PCoA2, with peak positive trends at intermediate values ($B_1 = -18.76 \pm 13.55$ SE, $t = -1.38$, $p = 0.176$ and $B_2 = -326.53 \pm 140.33$ SE, $t = -2.33$, $p = 0.027$ for the linear and quadratic terms, respectively; Fig. 4). Phylogenetic effects were negligible (lambda = 6.5e-05, chi-square = −0.0004 and lambda = 7.2e-05, chi-square = −0.0005 for the PCoA1 and PCoA2 models, respectively; df = 33, $p > 0.99$ in both cases). Larger steppe bird species with slower pace of life tended to experience more severe range contractions than smaller, fast-living species, consistent with findings from other taxa and guilds (Sæther et al., 2013). Steppe specialists and avian predators associated with tree patches (e.g., raptors other than harriers) exhibited stronger range contractions than generalist steppe birds.

3.3. *Overview of main threats to steppe birds*

The following summarizes the results of the expert-based review, which offers a detailed analysis of the current situation regarding the major threats to steppe birds and their habitats.

3.3.1. *Land use change*

In Europe, steppe bird diversity hotspots often occur in low human population density areas and rural agricultural landscapes, representing traditional extensively managed socio-ecological systems (e.g., Palacín et al., 2012). Despite supporting biologically valuable communities of endangered species, steppes are often perceived as landscapes of low economic and biodiversity value (Díaz et al., 2020), compared to wetlands or forests (García-Llorente et al., 2020). In recent decades, steppes with adequate edapho-climatic conditions or access to irrigation have faced agricultural intensification (Brotons et al., 2004; Silva et al., 2022, 2023b), while less productive steppes are increasingly threatened by industrial or renewable energy infrastructure development (Bolonio et al., 2024; Laiolo and Tella, 2006; Mañosa et al., 2020; Palacín et al., 2023; Serrano et al., 2020; Valera et al., 2022). Together, intensification, land abandonment, and infrastructure expansion drive habitat loss and degradation.

Addressing these challenges requires a comprehensive approach that balances biodiversity conservation with socio-economic needs. The conservation of steppe birds and their habitats is closely intertwined with the support of rural communities and the promotion of extensive land management practices. The main specific threats are:

a) agriculture expansion, intensification and specialization (Alonso et al., 2020b; Brotons et al., 2004; Cabodevilla et al., 2022; Cardador et al., 2015; Catry et al., 2012; De Frutos et al., 2015; Dengler et al., 2014; Giralt et al., 2021; Traba and Morales, 2019),
b) intensification of livestock management (Faria and Morales, 2020; Silva et al., 2023b),
c) conversion to woody crops, such as olive groves, traditional and trellis vineyards, pistachio and almond trees (Cabodevilla et al., 2021a; Casas et al., 2020; Díaz et al., 1998, 2022; Guerrero-Casado et al., 2022; Morgado et al., 2020, 2022),
d) afforestation promoted by agricultural policies (Díaz et al., 1998),
e) the abandonment of extensive agriculture or livestock in low productive areas (Catry et al., 2013; Traba and Pérez-Granados, 2022), and

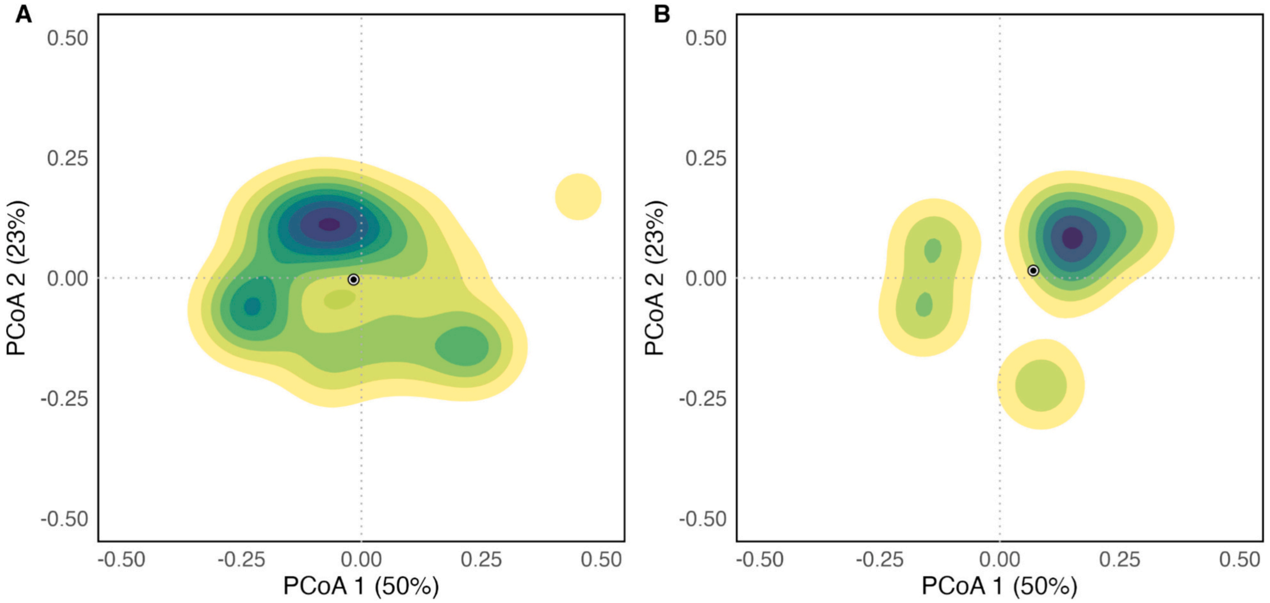

Fig. 3. Trait space for non-threatened (left) and threatened (right) steppe bird species, mapping the centroid of each type of steppe bird category (black and white dot) onto the ordination diagram. Positive values in PCoA1 are associated with large body size, high longevity and high reproductive investment (slow pace of life) and a preference for open habitats, whereas small-sized, and fast-lived species linked to semi-open habitats are associated with negative values. PCoA2 separates species with terrestrial lifestyle, ground foraging, ground nesting and sedentary behaviour, non-carnivorous diet, as well as small relative brain size (positive values), from species with aerial to insessorial lifestyles, with partial to full migratory behaviour, carnivorous diet, and large relative brain size (negative values).

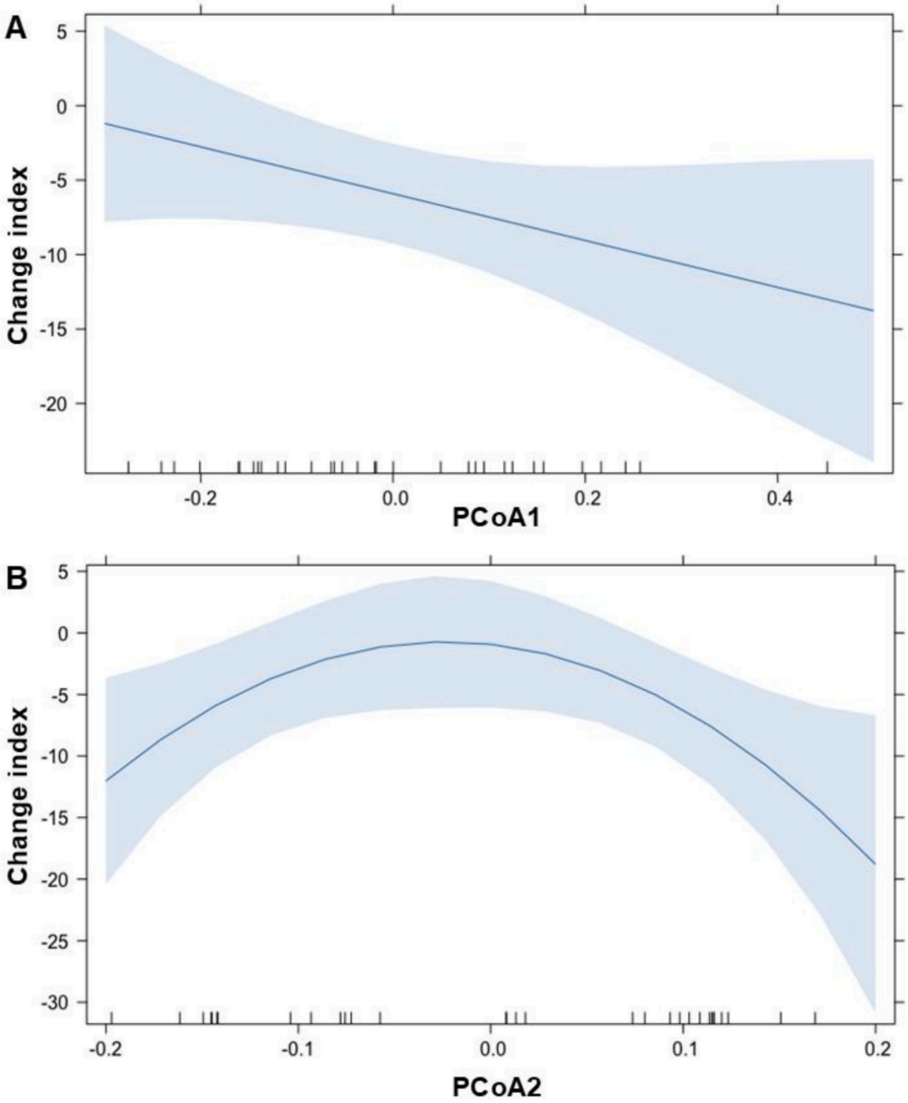

Fig. 4. Relationship between the range-change index (Appendix D) and species' positions within the trait space defined by the first two axes of the PCoA: A) PCoA1 and B) PCoA2. The mean (solid line) and the 95 % confidence interval (shaded area) are shown. Positive values in PCoA1 are associated with large body size, high longevity and high reproductive investment (slow pace of life) and a preference for open habitats, whereas small-sized, and fast-lived species linked to semi-open habitats are associated with negative values. PCoA2 separates species with terrestrial lifestyle, ground foraging, ground nesting and sedentary behaviour, non-carnivorous diet, as well as small relative brain size (positive values), from species with aerial to insessorial lifestyles, with partial to full migratory behaviour, carnivorous diet, and large relative brain size (negative values).

f) urbanization and development of large-scale human infrastructures (i.e. renewable energy plants, power lines, industrial areas and roads) (Arroyo et al., 2022; Bolonio et al., 2024; Gómez-Catasús et al., 2018; Hermoso et al., 2023; Illera et al., 2010; López-Jamar et al., 2011; Marcelino et al., 2018; Marques et al., 2020, 2021; Palacín et al., 2023; Santangeli et al., 2023; Serrano et al., 2020; Silva et al., 2022, 2023a; Torres et al., 2011; Valera et al., 2022).

The severity of these threats varies geographically and over time. For example, afforestation and woody crop expansion are more threatening in southern areas dominated by annual crops or in natural steppes (e.g. Concepción and Díaz, 2019; Kamp et al., 2015), while renewable energy impacts are driven by shifting global energy markets (Gómez-Catasús et al., 2024). However, in some cases, land use extensification have had positive impacts, such as the conversion of tree crops to low shrublands for extensive livestock grazing in southern Spain (López-Iborra et al., 2015).

3.3.2. *Increased human-induced mortality*

Human-induced mortality significantly lowers the survival rates of many steppe-land birds (Alonso et al., 2024a; Benítez-López et al., 2015; Marcelino et al., 2018; Šálek et al., 2019), contributing to their high extinction risk. Key causes include agricultural practices (e.g., ploughing and mowing during breeding), as well as starvation from reduced food supply due to intensive agricultural management (Casas and Viñuela, 2010; Ortiz-Santaliestra et al., 2020). Habitat fragmentation, urbanization, agricultural intensification, land abandonment, and loss of traditional activities increase the abundance and activity of mesopredators and/or anthropophilic predators, that threaten ground-nesting birds (Bravo et al., 2020, 2022; Gómez-Catasús et al., 2021; Gordon et al., 2017; McMahon et al., 2020; Šálek et al., 2015; Whittingham and Evans, 2004). High levels of nest and chick predation lead to severe reproductive failures for many ground-nesting species (e.g., Macdonald and Bolton, 2008; Roos et al., 2018). Collisions with power lines represent a major source of human-induced mortality for steppe birds, further endangering their populations (Marques et al., 2021; Palacín et al., 2017; Silva et al., 2022).

3.3.3. Unsustainable exploitation

Most steppe bird species are not hunted, traded, or exploited due to legal restrictions, as past hunting contributed to their current threatened status (e.g., great and little bustards, Marcelino et al., 2018; but not European golden plover or northern lapwing). Historically, Eurasian skylarks, calandra larks *Melanocorypha calandra*, and other species were heavily trapped for food in countries like Spain, Italy and France (Suárez et al., 2009), but this practice is now residual and does not significantly impact current population.

The red-legged partridge and the common quail remain important game species, at least in the Iberian Peninsula (Arroyo et al., 2012), but unsustainable management threatens their wild populations. Overhunting (Casas et al., 2016), hybridization with birds released for 'game restocking' (Blanco-Aguiar et al., 2008) and pathogen spillover (Cabodevilla, 2021; Villanúa et al., 2007) have contributed to their decline. Despite the millions of farm-raised birds being released annually for hunting purposes in Spain (Cabodevilla et al., 2020; Tarjuelo et al., 2021), hunting pressure has led to a 51 % decline in red-legged partridge density from 2010 to 2017 (Cabodevilla et al., 2021b), leading to its reclassification as Near Threatened by the IUCN. In turn, the range and population size of common quail in Spain have declined by at least 45.3 % and 50 %, respectively, over the last decades and the species has been proposed to be listed as Endangered nationally (Díaz, 2021; Medrano-Vizcaino et al., 2025). Migratory species face additional risks as hunting on breeding grounds can be exacerbated by hunting pressure on their migratory, wintering and/or stopover areas (Brochet et al., 2016; Kovacs et al., 2008). For instance, little bustards are legally hunted in parts of the Middle East and Asia during migration or at wintering grounds (Collar et al., 2017; Morales and Bretagnolle, 2022). Poaching of protected species, although in a minority, still persists (Benítez-López et al., 2015; Marcelino et al., 2018; Martín et al., 2007; Silva et al., 2022).

3.3.4. Pollution

The use of herbicides, pesticides, and fertilizers produces lethal or sublethal effects on birds and reduces the number and diversity of arable weeds and invertebrates, which are key for hosting food resources for farmland birds. Fertilizers, pesticides and veterinary products like ivermectin also impact dung and soil organisms, reducing habitat quality and food availability (Tonelli et al., 2017). These effects can extend beyond crop boundaries (Reverter et al., 2021) and are particularly acute during the breeding period when nestlings rely on invertebrates for food. Herbicides and pesticide-coated seeds have been linked to reduced breeding success in ground-nesting birds (Fernández-Vizcaíno et al., 2020; Gandara et al., 2024; Lopez-Antia et al., 2018; Ortiz-Santaliestra et al., 2020). Drip fertigation (i.e., injection of fertilizers into the irrigation system) may also negatively affect steppe birds (Cabodevilla et al., 2021a, 2022). While it reduces the amount of nitrates supplied, the remaining nitrates become highly concentrated in limited water resources in rainfed areas, potentially creating an ecological trap that attracts birds in summer. This issue requires further attention.

Other pollutants, such as noise pollution, can affect the behaviour of steppe birds. For example, little bustard males showed higher calling rates at sites with heavy traffic noise (Barrero et al., 2020), and wind turbine noise caused spectro-temporal shifts in Dupont's lark vocalizations (Gómez-Catasús et al., 2022). However, the broader implications of these vocal changes, such as their impact on energy expenditure or key communication functions (e.g., mate attraction and territory defense), remain unknown.

3.3.5. Invasive species

Invasive alien plant species are not currently a major threat to European steppe habitats, but certain steppe areas could face risks from their expansion in the future. Previous research in Europe and North America has suggested that invasive species may contribute to the encroachment of steppe habitats through the spontaneous spread of shrub vegetation, which may reduce habitat quality for open-habitat species, including most steppe birds (Nicolli et al., 2020). We lack knowledge about the potential impacts of invasive animals, plants, parasites or pathogens on steppe birds. Anecdotal evidence suggests that introduced domestic species, such as feral or free-ranging cats may be a problem (e.g. through nest predation) at least on a local scale (Illera and Díaz, 2006; Pérez-Granados et al., 2017). Similarly, the introduction of allochthonous species for hunting can result in hybridization of native species with unknown consequences on their populations (e.g., common quail; Puigcerver et al., 2013). In island-dwelling species, invasive parasites can also have negative consequences (Carrete et al., 2009; Illera et al., 2008).

3.3.6. Climate change

Climate change is a major driver of biodiversity loss, affecting all taxonomic groups, including steppe birds and their interactions (Ockendon et al., 2014). Due to their high metabolic rates and the need for efficient temperature regulation (Rastogui, 2007), steppe bird species are particularly vulnerable. Given projected climate change scenarios, increasing temperatures may negatively impact their range, reproduction, and survival (see for example, Catry et al., 2015; Kiss et al., 2020). Microclimate refugia may become essential for the persistence of steppe bird populations under these changing conditions (Ramos et al., 2023a,b), and conservation actions, such as nest-site provisioning, may need to be tailored to enhance the species' resilience to climate change (Catry et al., 2011).

Recent studies have demonstrated how extreme weather events can negatively impact population dynamics and breeding success of steppe birds (Alonso et al., 2024b; Illera and Díaz, 2006; Marcelino et al., 2020; Pérez-Granados et al., 2023; Ucero et al., 2024). Likewise, changes in rainfall regimes can result in significant population declines and even the collapse of steppe bird populations (Illera et al., 2024), likely due to impacts on survival rates (Delgado et al., 2009) and reproduction, which is primarily influenced by changes in food availability (Illera and Díaz, 2006). Severe storms can destroy nest clutches, further exacerbating reproductive challenges. High temperatures can increase inactivity, affecting breeding and foraging patterns, further compromising breeding success and overall population dynamics (Gudka et al., 2019; Silva et al., 2015). These conditions may also impose physiological stress on chicks and fledglings, negatively affecting growth and body condition (Catry et al., 2011, 2015). In some species, high summer temperatures may force individuals to migrate, increasing mortality risks (Alonso et al., 2009; Palacín et al., 2017). Climate change is also likely to constrain or shift the future distribution of steppe birds (Kiss et al., 2020), reducing connectivity among populations (Araújo et al., 2011; Estrada et al., 2016). Conversely, climate change may expand optimal habitats for thermophilic species (Ramón-Martínez and Seoane, 2024), such as collared pratincole *Glareola pratincola*, which has recently expanded its distribution range.

3.4. Species-specific threats and knowledge gaps

We collected threat assessments from 63 experts (Appendix F, Table F1), although the number of assessments varied across species (Appendix F, Table F2) and threats (Appendix F, Table F3). Land use change emerged as the primary driver of population declines, with the highest severity, scope and knowledge scores. Human-induced mortality was also identified as a key driver of population declines, with moderate severity and scope. In contrast, climate change, pollution, and unsustainable exploitation were deemed low-severity threats. Nonetheless, climate change affects a substantial proportion of populations (medium scope) and is associated with the least available knowledge (see, Illera et al., 2024). Invasive species were considered of lesser concern for

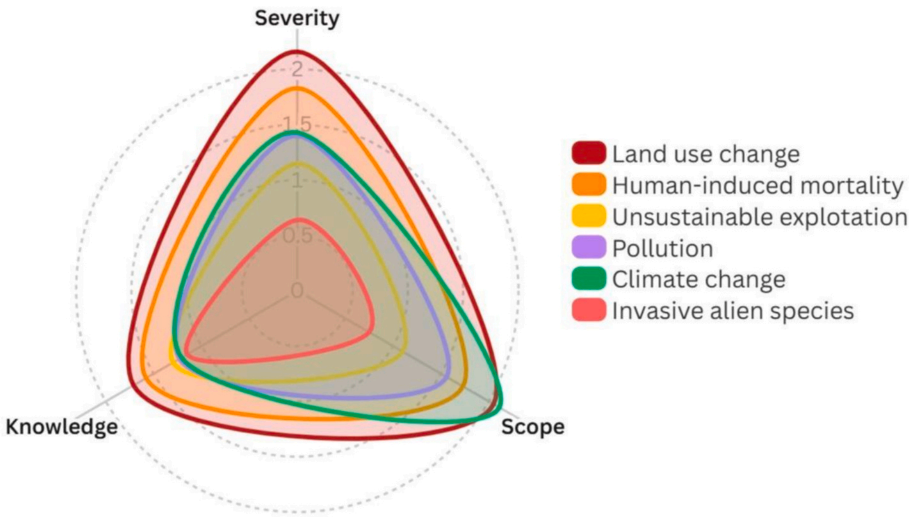

Fig. 5. Threats to steppe birds and their habitats as a function of their severity (i.e., the impact on population trends over 10 years or three generations, whichever is longer), scope (i.e., proportion of the total population affected), and knowledge available based on expert judgments (63 experts and 37 steppe-bird species). Scope and severity are categorized as Unknown (0), Low (1), Medium (2), High (3), and knowledge as Low (1), Medium (2), High (3).

steppe birds, affecting only a small fraction of populations, especially on mainland rather than island populations (Fig. 5; Appendix F, Table F1).

Threats decreased proportionally in scope, severity, and available knowledge, except for climate change which scored high in scope but ranked second lowest in knowledge (Fig. 5). Similarly, pollution was rated moderate in both scope and severity, yet knowledge of its impacts remains limited. Our results suggest that future research should prioritize evaluating the effects of climate change and pollutants on steppe bird populations and their habitats. While knowledge of invasive species and unsustainable exploitation is also limited, these factors do not appear to be major drivers of steppe bird declines, at least for the mainland species and populations.

Among the species assessed, the five with the least information on specific threats were black-eared wheatear *Oenanthe hispanica*, Iberian grey shrike, thekla lark *Galerida theklae*, stone curlew *Burhinus oedicnemus* and black-bellied sandgrouse (Appendix F, Table F2). Land use change impacts remain poorly understood for stone curlew and for both *Pterocles* species (Appendix F, Table F3). Significant knowledge gaps also exist regarding human-induced mortality on thekla lark, red-legged partridge, and common quail, and climate change impacts on Dupont's lark, Eurasian skylark, thekla lark, Iberian grey shrike, black-eared wheatear or black-bellied sandgrouse (Appendix F, Table F3). Pollution-related knowledge gaps are particularly evident for lesser kestrel, Iberian grey shrike, hen harrier *Circus cyaneus* and stone curlew. Understanding of unsustainable exploitation and invasive species aligns with their severity and scope scores (Appendix G). It is important to note that our focus is on threats within steppe environments, and threats faced in other habitats—such as during migration or for generalist species—may differ or pose distinct challenges.

4. Conclusions

This review updates and synthesizes the existing information on the population size, trends, and status of Western European steppe birds, and provides an overview of the main drivers of decline for these species. Additionally, it presents, for the first time, a characterization of the functional space of steppe birds and identifies traits associated with threat status and declining range trends. We established a consensual list of steppe bird species and found an alarming decline in this group of birds. Despite their declining trends, only 18.9 % of the species considered are currently listed as Endangered or Vulnerable on the IUCN Red List of Threatened Species at European level. This suggests that the status of several species, such as pin-tailed sandgrouse, great bustard, lesser short-toed lark, European roller, hen harrier, lesser kestrel, and crested lark *Galerida cristata* (among others with a declining index > 5 % but classified as Least Concern), warrants re-evaluation based on the most up-to-date information available (see Appendix D). Furthermore, substantial uncertainties in population estimates for certain species emphasize a critical need for more robust and comprehensive monitoring efforts. While we used EBBA data to standardize comparisons among species, more recent data are available for certain species, such as the great bustard (Alonso and Palacín, 2022), African houbara (Alonso et al., 2020a, 2024a; Carrascal, 2022; Ucero et al., 2021), or Canary Islands stonechat (Illera et al., 2024) (Appendix D). These updated datasets should be prioritized in species-specific re-evaluations.

The characterization of the functional space of steppe birds deepens our understanding of the traits that make a species more prone to extinction. Our findings indicate that traits are not randomly distributed according to threat status in steppe birds. Threatened species occupy a narrow yet distinct part of the functional space, dominated by large, long-lived species (but see, Illera et al., 2024) with ground-foraging and ground-nesting behaviours, along with sedentary tendencies-traits often associated with low reproductive rates and high sensitivity to environmental change, which likely contribute to their heightened extinction risk (see similar results in Seoane et al., 2011). These findings highlight that the most specialist steppe birds are also the most vulnerable ones (Guerrero et al., 2024), whereas non-threatened species occupy a broader functional space, reflecting a wider range of ecological strategies that may enhance their resilience to environmental pressures. This stark differentiation in functional space underscores the potential loss of functional diversity that will occur if the most vulnerable species become extinct, either locally or nationally. Our results also showed that species characterized by large size, long lifespan, terrestrial foraging, and ground nesting behaviour, as well as those with aerial to perching lifestyles, partial to full migratory behaviour, and carnivorous diet, are experiencing the greatest range declines, which helps infer particular drivers of change. These results could guide future research on the most threatened species and help identify inconsistencies among species experiencing significant range declines —such as great bustard, pin-tailed sandgrouse, and European roller— that are not currently listed as threatened by the IUCN at the European level.

Our expert-based threat assessment revealed that land use change is widely recognized as a main threat to steppe birds. The intensification and abandonment of land are opposing processes that, along with infrastructure development, drive habitat loss and fragmentation for steppe birds. Climate change has also emerged as a critical concern, altering habitat conditions and exacerbating the challenges faced by steppe ecosystems. As a large-scale driver, climate change could contribute significantly to population declines (e.g., Illera et al., 2024), affecting a substantial proportion of steppe bird species. However, potential positive effects have also been reported, warranting further investigation (e.g., Ramón-Martínez and Seoane, 2024). Additionally, human-induced mortality and unsustainable hunting exacerbate these threats. In contrast, invasive species and unsustainable exploitation appear to have a limited impact on steppe bird population declines, at least in the mainland. Despite progress in understanding these threats, significant knowledge gaps persist. In particular, the species-specific effects of climate change and pollutants—such as pesticides and fertilizers from intensive agriculture—remain poorly understood. These pollutants can accumulate in the environment, persisting over time, and cause severe and long-lasting damage to biodiversity (Geiger et al., 2010; Tonelli et al., 2017). Furthermore, there are significant data gaps concerning threats to specific species, including black-eared wheatear, Iberian grey shrike, thekla lark, stone curlew, and black-bellied sandgrouse. Targeted research efforts are urgently needed to fill these gaps, provide a more comprehensive basis for conservation strategies, and ensure the long-term persistence of these vulnerable species.

Overall, this review highlights that the conservation of steppe birds is an urgent challenge in the face of escalating global change drivers. Given the socio-ecological nature of steppe habitats, conservation strategies must be integrated with key human activities, such as agricultural management through the Common Agricultural Policy (Díaz et al., 2021; Pozuelo et al., 2024). However, the lack of comprehensive scientific evidence in many regions hampers effective conservation planning (Díaz et al., 2021; Pozuelo et al., 2024). The results presented here can help prioritize species, threats, and ecological factors that should be the focus of future research and conservation efforts. To tackle imminent threats such as land use changes, conservation actions must be based on solid, evidence-driven frameworks. Moreover, the role of administrations is critical in implementing land-use planning that balances human development and biodiversity conservation. This includes prohibiting harmful activities in sensitive areas while incentivizing sustainable practices that benefit wildlife. Ultimately, achieving long-term resilience of steppe ecosystems requires the active collaboration of scientists, policymakers, and local communities, using socio-ecosystem approaches that reflect the interconnectedness of human and environmental well-being (Pérez-Granados et al., 2025).

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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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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2025.111414.

Data availability

The data is attached as supplementary material

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