



## Short Communication

# Neither legal huntability nor harvest-based hunting interest explain broad-scale variation in population decline probability at the European scale

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## ABSTRACT

Understanding the drivers of bird population decline is central to evidence-based conservation policy. While habitat loss and land-use intensification are established pressures, the role of hunting in explaining large-scale population trends remains poorly understood. This study examines whether species listed as huntable under Annex II of the EU Birds Directive are more or less likely to show breeding population declines in Europe (assessed at the national scale), compared to those under strict protection (those in Annex I) or without designation. Building on a public EU-wide bird dataset, we incorporated national hunting status, and a proxy of hunting interest based on national harvest levels, to test whether hunting-related indicators are associated with differences in decline probability after accounting for ecological and policy-related covariates. Hypotheses included that hunting interest could reflect investment in habitat (thus reducing probability of population decline) or that hunting mortality is generally additive (thus increasing probability of population decline). The analysis focuses on breeding populations in nine countries with robust trend data, excluding species that breed elsewhere and overwinter in these areas. Results confirmed that Annex I designation was associated with reduced decline probability and showed that neither national legal huntability nor harvest-based hunting interest showed a statistically detectable association with population decline. This should not be interpreted as evidence that hunting has no effect: local species-specific impacts—positive or negative—may occur but remain undetectable at this scale. However, our findings point to the lack of consistent large-scale associations between the hunting-related indicators considered here and bird population trends across Europe.

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## 1. Introduction

Bird populations worldwide are declining at unprecedented rates, with Europe showing significant losses across multiple taxa (Inger et al. 2015; Rosenberg et al., 2019; Burns et al., 2021). While drivers such as habitat degradation, agricultural intensification, and climate change are well established (BirdLife International, 2022; Betts et al., 2022), the role of hunting on population trajectories remains the subject of continued debate. Hunting, including birds, is an ancient activity among humans (Gray et al., 2024) that is currently under debate. The conservation consequences of hunting remain strongly debated and appear to depend on ecological, socioeconomic and management context (Di Minin et al., 2021; Fromentin et al., 2023). On the one hand, hunting mortality can contribute to population decline when harvest is additive to other sources of mortality, particularly in populations already affected by other pressures (Péron, 2013; Buchan et al., 2022). On the other hand, recreational hunting may also generate incentives for habitat management, conservation investment and environmental stewardship (Estrada et al., 2015; Mustin et al., 2018; Shephard et al., 2024; Sánchez-García et al., 2024), potentially improving the conservation status of hunted animals.

The EU Birds Directive (Directive 2009/147/EC) provides the principal legislative framework for bird conservation across Member States. While all wild bird species are protected under this Directive, those listed in its Annex I require special conservation measures, including habitat protection, which are implemented at the national level. In contrast, Annex II identifies species that may be legally hunted, provided this is done sustainably and in accordance with national legislation. As a result, implementation of the Directive varies among Member States, leading to differences both in the conservation measures applied to Annex I species and in which Annex II species are legally hunted in each country.

This study builds upon the EU-wide avian trend dataset used by McMahon et al. (2024), which identified factors potentially associated with national-level bird population declines in 264 species across ten European countries, including legal protection status (Annex I list), nesting strategy (ground-nesting vs. other strategies), breeding habitat (agricultural or other), and farming intensity. The study found that ground-nesting species, as well as species breeding in farmland areas in countries with high farming intensity, had a higher probability of being in decline, whereas Annex I listing was associated with a lower probability of decline. Building on this dataset, we added national-level legal huntability and, for huntable species, a harvest-based proxy of hunting interest. For legally huntable species, we also compiled harvest information to derive a broad proxy of hunting interest based on the average number of individuals harvested across years. Our aim was to investigate whether breeding populations of species subject to legal hunting, or attracting different levels of hunting interest, differ in their probability of population decline after accounting for ecological and policy-related factors known to influence population trends. Rather than testing the direct demographic effects of hunting, this study evaluates whether broad hunting-related indicators are associated with large-scale patterns of population decline across European countries. Based on previous work, we considered two alternative predictions. If hunting mortality adds to other pressures, legally huntable species would be expected to show a higher probability of decline, with decline probability also increasing with harvest-based hunting interest (Péron, 2013; Buchan et al., 2022). Alternatively, if hunting interest is associated with habitat management, conservation investment and stewardship, legally huntable species could show a lower probability of decline, with decline probability decreasing as hunting interest increases (Di Minin et al., 2021; Mustin et al., 2018; Shephard et al., 2024).

## 2. Methods

### 2.1. Data compilation

We began with the dataset used in McMahon et al. (2024), which builds on ecological and management variables originally compiled in McMahon et al. (2020), and includes national population trend data from 264 bird species across European countries.

This dataset included information from European countries for which individual bird species data were freely available online, including an estimate of the long-term (two decades) trends for the species in that country. Trends for each species were categorized according to European Bird Census Council (EBCC) definitions (see <https://pecbms.info/methods/pecbms-methods/1-national-species-indices-and-trends/1-2-production-of-national-indices-and-trends/trend-interpretation-and-classification>) as 'important decline', 'moderate decline', 'stable', 'moderate increase', 'marked increase' or 'uncertain'. Quantitative data for the decline was not available for all countries (in some cases, only the categorical information was available). We regrouped the categories as 'decline' (either important or moderate) or 'no decline', (stable, moderate or marked increase, or uncertain trends) to obtain a binomial variable describing decline probability of a given species in each country (1 for 'decline' and 0 for 'no decline'). Additionally, information on each species included ecological attributes such as nesting strategy (ground-nesting or other) or association with agricultural habitats (whether farmland was the main breeding habitat, based on national reports or Tucker and Evans, 1997), and policy aspects such as Annex I designation. Furthermore, the data set also included information on country-level farming intensity (classified in three levels according to fertilizer and pesticide use, emissions, and percentage of organic farming; Eurostat and CAP Atlas, 2019). These variables have been shown in previous studies to influence population trajectories. More details are available in [Supplementary material](#).

This dataset was expanded with additional legal classification data. Each species was verified for designation under Annex II of the EU Birds Directive. For those included in Annex II, national regulations were checked to identify huntability at the national level. A new binary variable (national-level huntability) was constructed to indicate whether a species listed in Annex II could legally be hunted under national legislation (0 = not legally huntable; 1 = legally huntable). This variable therefore reflects legal hunting status rather than whether harvest actually occurred or the intensity of harvest.

Species with no Annex II designation were considered non-huntable, while those for which national hunting status could not be verified were excluded to maintain methodological rigour. This information was derived from Article 12 reports and national

legislation gathered in the Article 12 web tool (<https://nature-art12.eionet.europa.eu/article12/>). The final dataset consisted of 992 observations of 256 species across nine European countries—Spain, France, Hungary, Ireland, the Netherlands, Poland, Portugal, Sweden, and the United Kingdom—for which reliable information on national Annex II huntability status was available.

To further explore whether differences in hunting interest among huntable species were associated with population trends, we compiled harvest information from Article 12 reports (complemented with national sources when necessary) and calculated the average annual number of individuals harvested for each species-country combination across all available years (2013–2018). Because harvest information was not available for all huntable species or all countries included in the main dataset, this complementary analysis was restricted to a subset comprising 66 species-country observations representing 35 species across six countries (Spain [ES], France [FR], Hungary [HU], Poland [PL], Portugal [PT], and Sweden [SE]). Average harvest values were used as a broad proxy of hunting interest and classified into four ordered categories according to the mean number of individuals harvested annually: < 10,000 individuals ( $n = 20$  observations), 10,000–99,999 individuals ( $n = 23$ ), 100,000–499,999 individuals ( $n = 16$ ), and  $\geq 500,000$  individuals ( $n = 7$ ). This harvest-based hunting-interest variable was intended to reflect the relative socioeconomic importance of species to the hunting sector. This interpretation is supported by evidence that harvest levels are influenced not only by biological availability but also by hunter density, management decisions and economic investment (Delibes-Mateos et al., 2021). We nevertheless acknowledge that harvest magnitude may also be affected by factors such as population abundance, accessibility, hunting regulations and reporting practices, and therefore should not be interpreted as a direct measure of socioeconomic importance or hunting pressure. A complementary analysis was then conducted using this subset to test whether hunting interest was associated with the probability of population decline after accounting for the principal ecological and policy-related covariates included in the main analysis.

## 2.2. Statistical analysis

We fitted generalized linear mixed-effects models (GLMMs) with a binomial error distribution and logit link using the lme4 package in R (Bates et al., 2015). The response variable was national population decline status (1 = decline; 0 = no decline). Fixed effects included Annex I designation, nesting strategy, agricultural association, farming intensity, and national-level huntability. We additionally included two biologically motivated interactions: agricultural association  $\times$  farming intensity, following McMahon et al. (2024), and national huntability  $\times$  agricultural association, to test whether the association between huntability and population decline differed according to agricultural habitat association. Random intercepts for country and taxonomic order were included to account for non-independence among observations from the same country and among species belonging to the same taxonomic order. Models were fitted by maximum likelihood using the Bound Optimization BY Quadratic Approximation (BOBYQA) optimizer.

We initially fitted the complete a priori model containing both interactions. The huntability  $\times$  agricultural association interaction was unsupported and was subsequently removed to facilitate interpretation of the main effect of huntability, whereas the previously reported agricultural association  $\times$  farming intensity interaction was retained. Statistical significance of model terms in the final model was evaluated using likelihood-ratio tests based on single-term deletion. Model coefficients are reported on the logit scale with 95% Wald confidence intervals. Model fit was assessed by checking singularity and overdispersion. Multicollinearity among fixed effects was assessed using variance inflation factors (VIFs); all VIFs were below 3.4 in both the full and final models, indicating no problematic multicollinearity. Marginal and conditional  $R^2$  values were calculated to quantify variance explained by fixed effects and by the complete mixed model, respectively.

In addition, to evaluate whether variation in hunting interest was associated with population decline probability, we fitted a complementary model to the subset of huntable species for which harvest information was available. The model included Annex I designation, nesting strategy, agricultural association, farming intensity, and hunting interest as fixed effects. Hunting interest was primarily modelled as an ordinal variable coded from 1 to 4 according to increasing mean annual harvest (<10,000; 10,000–99,999;

**Table 1**

Fixed-effect estimates ( $\beta \pm \text{SE}$ ), 95% Wald confidence intervals, and likelihood-ratio tests from the final binomial generalized linear mixed-effects model of national population decline probability. Likelihood-ratio tests were obtained by single-term deletion. For factors with more than two levels, coefficients represent contrasts with the reference category. † Main effects involved in the retained agricultural association  $\times$  farming intensity interaction were not tested separately by single-term deletion to preserve model hierarchy. Random intercept variance (SD) was 0.284 (0.532) for taxonomic order and 0.164 (0.405) for country.

| Predictor/contrast                                                    | $\beta \pm \text{SE}$ | 95% CI         | LR $\chi^2$ | df | p-value |
|-----------------------------------------------------------------------|-----------------------|----------------|-------------|----|---------|
| <b>Intercept</b>                                                      | 0.183 $\pm$ 0.376     | −0.554, 0.919  |             |    |         |
| <b>Annex I designation (1 vs. 0)</b>                                  | −0.570 $\pm$ 0.192    | −0.946, −0.194 | 9.021       | 1  | 0.003   |
| <b>Nesting strategy</b>                                               |                       |                | 8.491       | 1  | 0.004   |
| Other vs. ground                                                      | −0.529 $\pm$ 0.180    | −0.881, −0.177 |             |    |         |
| <b>Agricultural association</b>                                       |                       |                | †           |    |         |
| Yes vs. no                                                            | 0.754 $\pm$ 0.299     | 0.169, 1.340   |             |    |         |
| <b>Farming intensity</b>                                              |                       |                | †           |    |         |
| Low vs. high                                                          | −0.213 $\pm$ 0.402    | −1.002, 0.575  |             |    |         |
| Medium vs. high                                                       | −0.783 $\pm$ 0.425    | −1.616, 0.051  |             |    |         |
| <b>National huntability (huntable vs. not huntable)</b>               | −0.087 $\pm$ 0.269    | −0.614, 0.440  | 0.104       | 1  | 0.747   |
| <b>Agricultural association <math>\times</math> Farming intensity</b> |                       |                | 11.945      | 2  | 0.003   |
| Agricultural yes $\times$ Low                                         | −0.342 $\pm$ 0.403    | −1.132, 0.448  |             |    |         |
| Agricultural yes $\times$ Medium                                      | 1.050 $\pm$ 0.433     | 0.202, 1.898   |             |    |         |

100,000–499,999; and  $\geq 500,000$  individuals), thereby testing for a monotonic linear trend in decline probability across increasing levels of hunting interest. Random intercepts for taxonomic order and country were initially included, as in the main analysis, but both variance components were estimated as zero and the model produced a singular fit. We fitted this analysis using a binomial generalized linear model (GLM) without random effects; fixed-effect estimates were identical to those obtained from the singular GLMM.

To assess whether our conclusions depended on assuming a linear trend across the four ordered hunting-interest categories, we conducted a sensitivity analysis in which hunting interest was instead fitted as a four-level categorical factor, allowing a non-linear relationship among categories. We compared the linear ordinal and categorical formulations using a likelihood-ratio test. Statistical significance of model terms was assessed using likelihood-ratio tests based on single-term deletion, and 95% Wald confidence intervals were calculated for model coefficients. All analyses were conducted in R version 4.5.2 (R Core Team, 2025).

### 3. Results

The interaction between national huntability and agricultural association was not supported (likelihood-ratio test:  $\chi^2 < 0.001$ ,  $df = 1$ ,  $p = 0.999$ ) and was therefore excluded from the final model. In the resulting model, Annex I designation, nesting strategy, and the interaction between agricultural association and farming intensity were significantly associated with national population decline probability (Table 1). In contrast, national-level huntability showed no additive effect on decline probability ( $\beta = -0.087$ , 95% CI =  $-0.614$  to  $0.440$ ; LRT  $\chi^2 = 0.104$ ,  $df = 1$ ,  $p = 0.747$ ; Table 1; Fig. 1A). This final model explained 9.5% of the variance through fixed effects (marginal  $R^2$ ) and 20.3% when both fixed and random effects were considered (conditional  $R^2$ ).

In the complementary analysis of 66 species-country observations for which harvest information was available, hunting interest showed no significant linear association with population decline probability ( $\beta = 0.212$ , 95% CI =  $-0.505$  to  $0.930$ ; LRT  $\chi^2 = 0.338$ ,  $df = 1$ ,  $p = 0.561$ ). Predicted decline probability increased slightly across increasing hunting-interest categories, but uncertainty was large and confidence intervals overlapped substantially (Fig. 1B). Importantly, this conclusion was robust to the treatment of hunting interest: modelling the four harvest categories as an unconstrained categorical factor, thereby allowing for non-linear differences among categories, also showed no overall association with decline probability (LRT  $\chi^2 = 4.072$ ,  $df = 3$ ,  $p = 0.254$ ). Moreover, the categorical model did not provide a significantly better fit than the simpler linear ordinal model (likelihood-ratio test:  $\chi^2 = 3.735$ ,  $df = 2$ ,  $p = 0.155$ ). Thus, we found no evidence that species associated with greater hunting interest were consistently more or less likely to exhibit population declines after accounting for the other ecological covariates.

### 4. Discussion

This study explored whether legal huntability and other broad hunting-related indicators are associated with national population trends once the principal ecological and management drivers previously identified by McMahon et al. (2024) are considered. Our analyses found no statistically significant association between legal huntability, and the probability of population decline at the national scale. This indicates that, based on the available data, we did not detect consistent evidence of either a positive or negative relationship between legal hunting permission and broad-scale population trends. We emphasize, however, that this relationship is purely correlational and should not be interpreted as evidence that hunting has no effect on population dynamics. The huntability

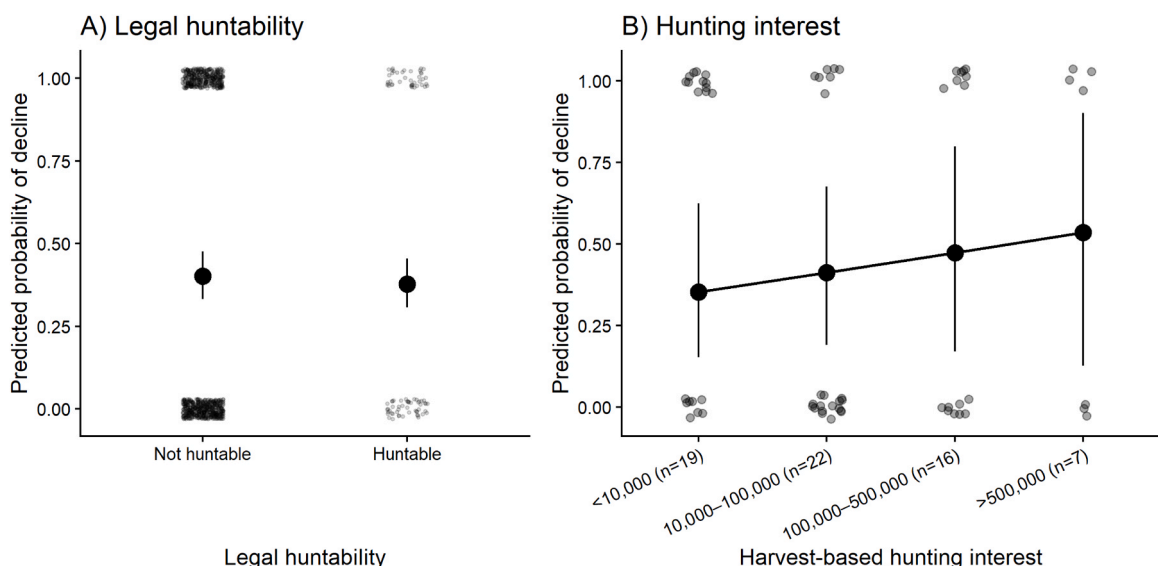


**Fig. 1.** Predicted probability of national population decline in relation to (A) legal huntability under Annex II and (B) harvest-based hunting interest among huntability species (expressed in number of individuals hunted). Points show raw binary decline data with jitter; black points and error bars show model-predicted probabilities and 95% confidence intervals.

variable only reflects the legal permission to hunt, not the actual harvest intensity, management effort, or local ecological context, all of which may differ substantially across species and countries. Such heterogeneity likely obscures local effects when data are aggregated at the national scale.

To further explore whether this result could be driven by the coarse nature of the huntability variable, the analysis restricted to huntable species and incorporating an ordinal proxy of hunting interest based on average national harvest levels showed no significant association between hunting interest and population decline probability. This conclusion was robust to alternative parameterizations of hunting interest, whether modelled as a linear ordinal gradient or as an unconstrained four-level categorical factor. Given the small harvest subset and the wide confidence intervals, the apparent direction of the estimated trend should not be interpreted as evidence of either a positive or negative association. Together, these findings indicate that we did not detect additional variation in broad-scale population trends associated with simple hunting-related indicators, whether based on legal status or harvest magnitude, beyond that already accounted for by the ecological and management variables included in the model. Because the broader ecological predictors included in the model, including Annex I designation, nesting strategy and breeding habitat, were analysed and discussed in detail by [McMahon et al. \(2024\)](#), we focus the discussion here on the newly evaluated hunting-related indicators.

Several factors could help explain why no overall association between huntability or harvest interest and broad-scale population trends was detected. Many huntable species are subject to local management (including habitat restoration, predator control or population reinforcement) aimed to boost or at least maintain populations ([Estrada et al., 2015](#); [Mustin et al., 2018](#); [McMahon et al., 2024](#); [Sánchez-García et al., 2024](#)), which aim to compensate impacts of extractive use. The absence of a detectable positive association between huntability or hunting interest and population trends may indicate that associated management actions are insufficient to offset the principal drivers of decline at this scale. Alternatively, beneficial management effects may occur locally but remain undetectable in national-scale population trends, particularly if the intensity and effectiveness of management vary substantially among species, regions and countries. Additionally, it has been shown that species-specific ecological traits and pressures can mediate hunting impacts. For example, populations already declining due to habitat loss or low productivity may be more vulnerable to additional pressures such as hunting mortality ([Péron, 2013](#); [Buchan et al., 2022](#); [Liang et al., 2025](#)), and such dynamics are unlikely to be fully captured in this broad-scale assessment. Future research integrating species-level management information, such as the presence of conservation programmes, hunting intensity, and demographic responses to management actions would help clarify how these mechanisms influence observed patterns.

Finally, we note that the categorical nature of EU-wide trend data, together with the broad nature of our explanatory variables, constrains the level of statistical resolution achievable at this scale. While future harmonised datasets containing continuous trend estimates with uncertainty values, coupled with quantitative data on hunting intensity relative to population abundance and demographic capacity ([Ellis and Cameron, 2022](#)), may enable more refined analyses, the current binomial classification remains the most robust and comparable option for cross-national assessments. In addition, this binary approach aligns with conservation decision-making frameworks, which prioritise determining whether a species is declining or not as a trigger for management interventions, rather than quantifying the exact rate of change. Additionally, our dataset is not fully comprehensive, as it includes mostly Annex II species that are common and widely distributed across countries. This may limit the detection of effects on less common or more localized species.

Overall, our findings should be seen as a first, large-scale exploratory assessment. Neither legal huntability nor harvest-based hunting interest was significantly associated with population decline probability at the national scale, and the latter conclusion was robust to alternative treatments of hunting interest as either a linear ordinal gradient or an unconstrained categorical variable. These results contrast with the significantly lower decline probability associated with Annex I designation, previously discussed by [McMahon et al. \(2024\)](#), reinforcing the importance of formal conservation measures under the Birds Directive. Future analyses incorporating detailed hunting bag data, population abundance, management plans, demographic information, and spatially explicit population trends are needed to better understand the conditions under which hunting may either exacerbate or mitigate population declines ([Buchan et al., 2022](#); [Fromentin et al., 2023](#)). Rather than indicating an absence of hunting effects, our results suggest that broad-scale indicators of hunting status or harvest magnitude may be insufficient to capture the complex interactions among legal frameworks, management practices, ecological variability, and demographic processes that ultimately shape population trajectories.

### CRediT authorship contribution statement

EdP analysed the data and wrote the first draft of the manuscript, BA and BMcM had the initial idea for the manuscript, MCF collated the data in collaboration with EdP. All authors read, edited and approved the final version of the manuscript.

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### Declaration of Competing Interest

The authors have nothing to declare.

## Data availability statement

The database and R code used in this study are available in the following repository: [10.6084/m9.figshare.29492138](https://doi.org/10.6084/m9.figshare.29492138).

## Declaration of Competing Interest

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

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.gecco.2026.e04418](https://doi.org/10.1016/j.gecco.2026.e04418).

## Data availability

Data will be made available on request.

## References

- Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67 (1), 1–48. <https://doi.org/10.18637/jss.v067.i01>.
- Betts, M.G., Yang, Z., Hadley, A.S., Smith, A.C., Rousseau, J.S., Northrup, J.M., Nocera, J.J., Gorelick, N., Gerber, B.D., 2022. Forest degradation drives widespread avian habitat and population declines. *Nat. Ecol. Evol.* 6, 709–719. <https://doi.org/10.1038/s41559-022-01737-8>.
- BirdLife International, 2022. State of the World's birds 2022: insights and solutions for the biodiversity crisis.
- Buchan, C., Franco, A.M.A., Catry, I., Gamero, A., Klvaňová, A., Gilroy, J.J., 2022. Spatially explicit risk mapping reveals direct anthropogenic impacts on migratory birds. *Glob. Ecol. Biogeogr.* 31, 1707–1725. <https://doi.org/10.1111/geb.13551>.
- Burns, F., Eaton, M.A., Burfield, I.J., Klvaňová, A., Šilarová, E., Staneva, A., Gregory, R.D., 2021. Abundance decline in the avifauna of the European Union reveals cross-continental similarities in biodiversity change. *Ecol. Evol.* 11, 16647–16660. <https://doi.org/10.1002/ece3.8282>.
- CAP Atlas, 2019. The Common Agricultural Policy Atlas: Indicators of CAP Performance and the Post-2020 Reform. Heinrich Böll Foundation, BirdLife International, European Environmental Bureau, Brussels.
- Delibes-Mateos, M., Moreno-Zarate, L., Peach, W., Arroyo, B., 2021. Estate-level decision-making and socioeconomics determine annual harvest in the European Turtle-dove in central Spain. *Sci. Total Environ.* 791, 148168. <https://doi.org/10.1016/j.scitotenv.2021.148168>.
- Di Minin, E., Clements, H.S., Correia, R.A., Cortés-Capano, G., Fink, C., Haukka, A., Hausmann, A., Kulkarni, R., Bradshaw, C.J.A., 2021. Consequences of recreational hunting for biodiversity conservation and livelihoods. *One Earth* 4, 238–253. <https://doi.org/10.1016/j.oneear.2021.01.014>.
- Ellis, M.B., Cameron, T.C., 2022. An initial assessment of the sustainability of waterbird harvest in the United Kingdom. *J. Appl. Ecol.* 59, 2839–2848. <https://doi.org/10.1111/1365-2664.14281>.
- Estrada, A., Delibes-Mateos, M., Caro, J., Viñuela, J., Díaz-Fernández, S., Casas, F., Arroyo, B., 2015. Does small-game management benefit steppe birds of conservation concern? A field study in central Spain. *Anim. Conserv.* 18 (6), 567–575. <https://doi.org/10.1111/acv.12211>.
- Fromentin, J.-M., Emery, M.R., Donaldson, J., Balachander, G., Barron, E.S., Chaudhary, R.P., Danner, M.-C., Gasalla, M.A., Hallosserie, A., Halmy, M., Hicks, C., Kieling, D., Park, M.S., Parlee, B., Rice, J., Ticktin, T., Tittensor, D., 2023. Status, challenges and pathways to the sustainable use of wild species. *Glob. Environ. Change* 81, 102692. <https://doi.org/10.1016/j.gloenvcha.2023.102692>.
- Gray, A., Doyle, S., Doyle, C., Young, J.C., McMahon, B.J., 2024. Birds and human health: pathways for a positive relationship and improved integration. *Ibis* 166, 455–471. <https://doi.org/10.1111/ibi.13290>.
- Inger, R., Gregory, R.D., Duffy, J.P., Stott, I., Voříšek, P., Gaston, K.J., 2015. Common European birds are declining rapidly while less abundant species' numbers are rising. *Ecol. Lett.* 18, 28–36. <https://doi.org/10.1111/ele.12387>.
- Liang, D., Mu, T., Yang, Z., Wang, Y., Li, J., Huang, M., Liu, Y., Song, L., Cai, S., Zhang, X., Wang, Y., Liao, Z., Fan, S., Noon, B.R., Giam, X., Liu, Y., Wilcove, D.S., 2025. Direct mortality due to humans threatens migratory shorebirds. *Nat. Ecol. Evol.* 9, 2080–2091. <https://doi.org/10.1038/s41559-025-02848-8>.
- McMahon, B.J., Doyle, S., Gray, A., Kelly, S.B.A., Redpath, S.M., 2020. European bird declines: do we need to rethink approaches to the management of abundant generalist predators? *J. Appl. Ecol.* 57, 1885–1890. <https://doi.org/10.1111/1365-2664.13695>.
- McMahon, B.J., Doyle, S., Mougeot, F., Arroyo, B., 2024. The decline of ground-nesting birds in Europe: do we need to manage predation in addition to habitat? *Glob. Ecol. Conserv.* 55, e03213. <https://doi.org/10.1016/j.gecco.2024.e03213>.
- Mustin, K., Arroyo, B., Beja, P., Newey, S., Irvine, R.J., Kestler, J., Redpath, S.M., 2018. Consequences of game bird management for non-game species in Europe. *J. Appl. Ecol.* 55, 2285–2295. <https://doi.org/10.1111/1365-2664.13131>.
- Péron, G., 2013. Compensation and additivity of anthropogenic mortality: life-history effects and review of methods. *J. Anim. Ecol.* 82 (2), 408–417. <https://doi.org/10.1111/1365-2656.12014>.
- R Core Team, 2025. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
- Rosenberg, K.V., Dokter, A.M., Blancher, P.J., Sauer, J.R., Smith, A.C., Smith, P.A., Stanton, J.C., Panjabi, A.O., Helft, L., Parr, M.J., Marra, P.P., 2019. Decline of the North American avifauna. *Science* 366, 120–124. <https://doi.org/10.1126/science.aaw131>.

- Sánchez-García, C., Powolny, T., Lormée, H., Dias, S., Sardà-Palomera, F., Bota, G., Arroyo, B., 2024. Habitat management carried out by hunters in the European Turtle Dove (*Streptopelia turtur*) western flyway: opportunities and pitfalls for linking with sustainable hunting. J. Nat. Conserv. 78, 126561. <https://doi.org/10.1016/j.jnc.2024.126561>.
- Shephard, S., von Essen, E., Gieser, T., List, C.J., Arlinghaus, R., 2024. Recreational killing of wild animals can foster environmental stewardship. Nat. Sustain. 7, 956–963. <https://doi.org/10.1038/s41893-024-01379-7>.
- Tucker, G.M., Evans, M.I., 1997. Habitats for Birds in Europe: A Conservation Strategy for the Wider Environment, 6. BirdLife International, Cambridge.