Biological Conservation 298 (2024) 110755

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

The importance of locally sourced data in identifying population trends: Insights from Iberian vertebrates

Roberto C. Rodríguez-Caro [a,b,*], Zebensui Morales-Reyes [c], Alba Aguión [d], Rebeca Arias-Real [e], Eneko Arrondo [f], Eneko Aspillaga [g], Jordi Boada [h], Andrea Campos-Candela [i], Mónica Expósito-Granados [j], Aitor Forcada [k], Robin Freeman [l], Miguel Ángel Gómez-Serrano [m,n], Cayetano Gutiérrez-Cánovas [o], Roberto Pascual-Rico [p], Valentina Marconi [l], Maria Montseny [q,r], Andreu Rotger [s], Graciel·la Rovira [q], Amalia Segura [t], Iván Sola [k], Carlos Valle [k], Pol Capdevila [q,r]

[a] *Departamento de Ecología, Universidad de Alicante, San Vicent del Raspeig 03690, Alicante, Spain*
[b] *Department of Biology, University of Oxford, 11a Mansfield Road, OX1 3SZ Oxford, UK*
[c] *Instituto de Estudios Sociales Avanzados (IESA), CSIC, Plaza Campo Santo de los Mártires, 7, 14004 Córdoba, Spain*
[d] *Coasts and Commons Co-Lab, Nicholas School of the Environment, Duke University, USA*
[e] *Museo Nacional de Ciencias Naturales, Consejo Superior de Investigaciones Científicas, Serrano 115 bis, 28006 Madrid, Spain*
[f] *Departmento de Zoología, Universidad de Granada, Spain*
[g] *Instituto Mediterráneo de Estudios Avanzados (IMEDEA, CSIC-UIB), 07190 Esporles, Illes Balears, Spain*
[h] *Centre d'Estudis Avançats de Blanes (CEAB-CSIC), 17300 Blanes, Girona, Spain*
[i] *Department of Biological Sciences, University of Bergen, Bergen 5020, Norway*
[j] *Departmento de Biología, Institute of Marine Science INMAR, Universidad de Cádiz, Cádiz, Spain*
[k] *Department of Marine Sciences and Applied Biology, Universidad de Alicante, Alicante, Spain*
[l] *Institute of Zoology, Zoological Society of London, Regent's Park, London NW1 4RY, UK*
[m] *Department of Microbiology and Ecology, Faculty of Biological Sciences, Universidad de Valencia, E-46100 Burjassot, Valencia, Spain*
[n] *Servicio de Vida Silvestre y Red Natura 2000-Generalitat Valenciana, Spain*
[o] *Biodiversity and Conservation Area, Universidad Rey Juan Carlos, Tulipán s/n, 28933 Madrid, Spain*
[p] *Grupo SaBio, Instituto de Investigación en Recursos Cinegéticos (IREC), UCLM-CSIC-JCCM, Ronda de Toledo S/N, 13005 Ciudad Real, Spain*
[q] *Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals, Facultat de Biologia, Universitat de Barcelona (UB), Barcelona 08028, Spain*
[r] *Institut de Recerca de la Biodiversitat (IRBio), Universitat de Barcelona, Barcelona 08028, Spain*
[s] *Animal Demography and Ecology Unit, GEDA – IMEDEA (CSIC/UIB), c. M Marques, 21, 01790 Esporles, Spain*
[t] *Departamento de Biología Aplicada, Universidad Miguel Hernández de Elche, 03203 Elche, Spain*

ARTICLE INFO

Keywords:
Abundance
Amphibia
Aquatic ecosystems
Biomass
Conservation status
Demography
Density
Population dynamics

ABSTRACT

Understanding species population trends is key for assessing their conservation status and proposing measures to ensure their future persistence amid recent biodiversity loss. However, studies are reporting contrasting biodiversity trends over time. These discrepancies can be partly attributed to biases in global datasets, which might not capture the representativeness of local processes. Here, we aimed to address this gap of knowledge by complementing data included in the Living Planet Database (LPD), one of the largest repositories of population time-series, with locally sourced data from the Iberian Peninsula. The study aim: (i) to assess the state of wildlife Iberian vertebrates using population time-series across taxonomic groups and (ii) to determine differences between locally sourced data and LPD (evaluating also the differences between data sources). To supplement LPD, we conducted a review, analysing over 6000 peer-reviewed manuscripts and grey literature documents. We obtained 999 population time-series for 294 vertebrate species compiled in an Iberian Vertebrate (IbeV) database, two times the number of populations as the LPD includes. Our results indicate contrasting population trends

---

* Corresponding author at: Departamento de Ecología, Universidad de Alicante, San Vicent del Raspeig 03690, Alicante, Spain.
E-mail addresses: r.rodriguez@umh.es (R.C. Rodríguez-Caro), zmorales@iesa.csic.es (Z. Morales-Reyes), alba.aguion@duke.edu (A. Aguión), rebeca.arias@mncn.csic.es (R. Arias-Real), aspillaga@imedea.uib-csic.es (E. Aspillaga), jboada@ceab.csic.es (J. Boada), andrea.campos-candela@uib.no (A. Campos-Candela), monica.exposito@uca.es (M. Expósito-Granados), forcada@ua.es (A. Forcada), robin.freeman@ioz.ac.uk (R. Freeman), miguel.gomez@uv.es (M.Á. Gómez-Serrano), cayetano.gutierrez@urjc.es (C. Gutiérrez-Cánovas), roberto.pascual@uclm.es (R. Pascual-Rico), valentina.marconi@ioz.ac.uk (V. Marconi), graciellarovira@ub.edu (G. Rovira), ivan.sola@ua.es (I. Sola), carlos.valle@ua.es (C. Valle), pcapdevila@ub.edu (P. Capdevila).

https://doi.org/10.1016/j.biocon.2024.110755
Received 4 May 2024; Received in revised form 31 July 2024; Accepted 5 August 2024

across taxonomic groups, with freshwater amphibians and bony fishes showing steep declines. Moreover, the LPD shows a positive trend and IbeV indicates no net change over time. Threatened species did not exhibit net changes in population trends, while non-threatened species showed positive trends. We showed that local databases can provide distinct population trends compared to global databases. This approach highlights the need to bridge the gap between global and local datasets, to support context-specific management and conservation programmes.

---

1. Introduction

The Anthropocene is unfolding a change in biodiversity at a global scale (Díaz et al., 2019). According to the latest Living Planet Report, the relative abundance of wildlife populations has declined by 69 % on average since 1970 (WWF, 2022), and global estimates predict that approximately one million species will become extinct in the coming decades (Barnosky et al., 2011; IUCN, 2022). Because species play key ecological roles in Earth's varied ecosystems, their loss is expected to cause dramatic consequences for the functioning and the resilience of ecosystems worldwide (Barnosky et al., 2012; Carmona et al., 2021; Capdevila et al., 2022). Therefore, wildlife monitoring has become a key priority for understanding and anticipating the magnitude of the anthropogenic impacts on biodiversity.

Despite the decline of biodiversity, some studies have counter-argued this general assumption, reporting positive or no net changes in populations or species abundance over time (Dornelas et al., 2019; Daskalova et al., 2020b; Leung et al., 2020). Some of the reasons that have been put forward for these discrepancies are related to the inherent biases within the datasets (Gonzalez et al., 2016; Dornelas et al., 2019; Murali et al., 2022). Many datasets also come from collections of peer-reviewed manuscripts, which tend to report declining trends (Donaldson et al., 2016). Another reason for these negative trends is the biases of human interest of different taxonomic groups and systems (Bowler et al., 2015; Khaliq et al., 2015; Daskalova et al., 2020b). For example, amphibians show the most pronounced declines (Hoffmann et al., 2010; Leung et al., 2017); however, they are often poorly represented in global population datasets (Daskalova et al., 2020b; WWF, 2022). Furthermore, positive trends can be found when population time-series come from protected areas, which may undermine the real loss of wildlife populations (Murali et al., 2022).

Despite the utility of global datasets to reveal net population trends, the global trends can mask contrasting responses at finer spatial scales (McGill et al., 2015; Daskalova et al., 2020b). Identifying where local declines occur is key to develop conservation measures, particularly because global conservation assessments do not necessarily reflect the status of species at local scales (Martín-López et al., 2011; Gamelon et al., 2017). Although these local trends are crucial to design appropriate management and conservation policies by local and regional authorities, "in situ" comparisons of population trends across spatial scales are yet to be conducted for most taxa and regions (Gonzalez et al., 2016). In addition, global databases cannot cover all the information available in each region due to the limited accessibility of some datasets (e.g., due to linguistic or peer-review/public available information) or the lack of capacity (data searcher are limited to specific funded projects). This lack of capacity can be the case of data time-series collected from monitoring plans established by environmental regulations with specific objectives. For example monitoring programs aiming to identify possible impacts of effluents from different industries (e.g. desalination or sewage treatment plants) on marine environment, and therefore to detect whether local populations remain stable over time (Stewart-Oaten et al., 1986; Sola et al., 2020). Thus, in-depth local studies can provide crucial knowledge regarding the processes driving population changes at the local scale (van Strien et al., 2016).

In this study, we explored the population trends of marine, terrestrial, and freshwater vertebrates across the Iberian Peninsula at the local scale. We focused on the Iberian Peninsula due to its importance as a biodiversity hotspot (Gómez and Lunt, 2007), and because of its growing exposure to global change threats (Martins et al., 2014; Barredo et al., 2016; Garrabou et al., 2022). Moreover, the presence of several languages in the territory means that it is difficult to include regional and local databases in global biodiversity studies (Amano and Sutherland, 2013; Chowdhury et al., 2022). For these reasons, comparing the available information from global databases with the information obtained from local sources in the Iberian Peninsula can provide useful and novel insights about vertebrate population trends and their conservation status. Our study introduces a novel approach for comparing databases, potentially setting a precedent for aligning general trends with local diagnoses, which is crucial for effective conservation measures.

Therefore, this study aims to provide key information about the state of wildlife species in the Iberian Peninsula. Specifically, we: i) describe vertebrate population trends in the Iberian Peninsula based on local information and detect data gaps related to taxonomic groups and habitat systems; and ii) evaluate the differences in population trends obtained from global and local datasets. We expected to find a variety of population trends across the Iberian Peninsula with a mismatch between the population trends derived from global and local datasets (hypothesis 1; H1), primarily due to the under-representation of non-charismatic or less abundant species in global datasets (Martín-López et al., 2009; Martín-Forés et al., 2013). We also hypothesized that population time-series from peer-reviewed manuscripts would show stronger declines than those from grey literature (H2), given the inherent bias in the publishing system, mostly reporting declines (Donaldson et al., 2016). Finally, we expected to find data gaps for some taxa, especially amphibians and reptiles (H3), which are generally the least studied vertebrate groups (Conde et al., 2019).

2. Methods

2.1. Systematic review

To obtain the time-series of vertebrate populations across the Iberian Peninsula, we conducted a systematic literature review of peer-reviewed scientific publications (hereafter, peer-review) and grey literature. We limited the search to vertebrate groups given the large number of existing long-term population monitoring programs, and because these are the taxonomic groups primarily covered by the Living Planet Database (LPD) (Loh et al., 2005; Collen et al., 2009). Our review included three habitat systems (terrestrial, marine, and freshwater). We followed the guidelines for systematic reviews by Pullin and Knight (2009), which involved implementing a rigorous protocol for conducting article searches and establishing inclusion criteria to promote transparency and mitigate potential bias. We used the Scopus database to search for peer-reviewed scientific literature. We created a search string that combined different terms related to vertebrate groups, geographical area of study (Iberian Peninsula) and population trends (see Appendices S1 and S2 for the full search string).

The search was applied to titles, abstracts, and keywords of peer-reviewed articles (i.e., excluding book chapters and conference papers) in English, Portuguese, Spanish, Catalan, Valencian, and Galician (the main languages in the region and understood by the authors) from 2000 to 2019, yielding 6968 articles. To identify relevant studies, we conducted a two-step review process among the selected articles (Appendix S3: Fig. S1), where we first conducted an initial screening based on the information available in the title and abstract, and then a full-text screening of the article. After the screening process, we applied seven inclusion criteria. Specifically, we selected articles written in previously mentioned languages (criterion 1) that empirically (criterion 2) investigated population trends of one or more wild vertebrate species, excluding invasive or exotic species (criterion 3) in the Iberian Peninsula and/or Balearic Islands (criterion 4), for at least five years (criterion 5), with consistent sampling efforts (criterion 6), while excluding historical studies such as paleogeographic studies (criterion 7) (see Appendix S4 for details of inclusion criteria). The two-stage review process was conducted by all co-authors (double-checked, meaning that data collected by one author was checked by a second one) to ensure comprehensive identification of potentially eligible studies. After the initial title and abstract screening, 696 articles were identified for full-text screening, of which 137 met the criteria and were therefore selected for in-depth analysis.

Using a systematic approach, we developed a coding scheme to structure the database, focusing on six sets of variables (see Appendix S5 for the full list): (i) general description (e.g., creation date, data source type, etc.), (ii) taxonomic information, (iii) location data, (iv) system (marines, terrestrial and freshwater), (v) trends data, and (vi) conservation status.

To obtain abundance data over time from the scientific papers, we used the raw data provided within the manuscript. When articles did not have supplementary or archived data, we contacted the authors directly. When none of the above was available but we have the figure in the manuscript with the time-series, we used the *metaDigitise* R package (Pick et al., 2019) using the scale of the figure and to digitise each value of the time-series by hand in R v4.0.0 (R Core Team, 2020). These criteria resulted in our Iberian database of local population trends (hereafter, Iberian Vertebrates 'IbeV'), consisting of a total of 558 time-series of vertebrate populations extracted from 124 articles (see Appendix S6).

2.2. *Final dataset*

We complemented the dataset obtained in our literature search with data from the LPD (www.livingplanetindex.org) (Loh et al., 2005; Collen et al., 2009) and grey literature. The LPD was used because it is one of the largest vertebrate population time-series databases, containing 38,000 time-series of population abundances of 5000 vertebrate species worldwide. We selected LPD time-series for the Iberian Peninsula and the Balearic Islands (in addition to the restrictions applied to the systematic review), which resulted in 544 more time-series. Finally, we searched for grey literature data by contacting different national organisations which develop long-term monitoring and public administrations in Spain and Portugal, where biodiversity monitoring programmes were held, which provided 441 additional local time-series that matched our selection criteria (see Appendix S4 for details of inclusion criteria).

Once all data were gathered and assembled, we removed duplicated time-series across the three independent datasets (literature search, LPD and grey literature). We defined duplicate time-series as those targeting the same species and location from the same study (e.g., population trend of the spur-thighed tortoise, *Testudo graeca*, in Murcia is available in the LPD and the IbeV database with the same reference: Rodríguez-Caro et al. (2016)). To gauge the net contribution of our literature search to global databases (in this case the LPD), we removed duplicate records from our newly assembled dataset. When replicates (same species and location from different studies) were detected among the studies that we found in the literature search, or between our literature search and the grey literature, we kept those with the longest time span to better represent population trends. For example, the population of white storks, *Ciconia ciconia*, in Doñana National Park was reported in Ramo et al. (2013) for 26 years and in Rendón et al. (2008) for 27, we therefore used the latter time-series. Overall, our final dataset contained 1543 time-series for 430 vertebrate species.

2.3. *Ancillary data*

First, we standardised the taxonomic information for the species in the dataset using "gnr_resolve" function from the *taxize* R package (Chamberlain and Szöcs, 2013) resolving for the Global Biodiversity Information Facility Backbone Taxonomy. In order to classify the species according to the system (terrestrial, marine, or freshwater) they inhabit, we used the information contained in the IUCN (IUCN, 2022) database using the function "rl_search" from the *redlist* R package (Chamberlain, 2020). When a given species was found in more than one system (e.g., amphibians use both freshwater and terrestrial systems), a combination of the inhabited systems were included (e.g., Terrestrial/Freshwater).

The taxonomic group of each species was assigned according to the most updated taxonomy available. We grouped Actinopterygii and Sarcopterygii under the category of "bony fishes". Each time-series was assigned to a database (either LPD or IbeV). Based on the data source within each database, we also differentiated between grey literature or peer-review publications. In some cases, within the LPD, the data source could not be identified, so it was classified as "unknown".

Finally, we used the conservation status of the species according to the IUCN Red List criteria (IUCN, 2022). To simplify the conservation status categorisation, we pooled the categories Least Concerned and Near Threat as "non-threatened" and Vulnerable, Endangered and Critically Endangered as "threatened". We categorised species classified as Data Deficient or Not Evaluated as "unknown".

Additionally, to ensure that our data was not being biased by the benefits of protected areas we classified population time-series according to whether they were inside or outside protected areas. We considered protected areas those areas included in the Natura 2000 network for terrestrial and freshwater species, and areas with restricted fishing activities for marine species. When we were unable to identify the exact location, we categorised the location as "unknown".

For each time-series, we categorised the information related to (i) system (i.e., freshwater, freshwater/terrestrial, marine, marine/freshwater, marine/freshwater/terrestrial, marine/terrestrial, terrestrial), (ii) taxonomic group (i.e., Amphibia, Aves, Bony fishes, Elasmobranchii, Mammalia, Reptilia), (iii) database (i.e., IbeV, LPD), (iv) data source (i.e., grey literature, peer-review, unknown), (v) conservation status (i.e., non-threatened, threatened, unknown), and (vi) area protected or not, to further explore the influence of these factors on the reported population trends.

2.4. *Quantifying population trends*

To estimate the population trends from the different time-series, we used a discrete-time, exponential growth state-space model (Dennis et al., 2006; Humbert et al., 2009). State-space models allow to estimate population trends (μ) while accounting for the variance in the trends caused by process error (σ^2) and observation or measurement error (τ^2) (Dennis et al., 2006, Humbert et al., 2009). Where μ here represents the annual population rate of increase. Instead of using the raw abundance at a given time to fit the models, we used the natural logarithm of the abundance at a given time plus the 1 % of the maximum abundance of the time-series (because estimates for the state-space models cannot be below one) (Dennis et al., 2006):

$$Ln\left(Abundance + \frac{max(Abundance)}{100}\right), \tag{1}$$

Our state-space models took the general form given by:

$$X_t = X_{t-1} + \mu + E_t, \tag{2}$$

where X_t represents the observed abundance (Eq. (1)) at time t, X_{t-1} is the observed abundance (Eq. (1)) from the previous year ($t-1$), and E_t is the process noise with a Gaussian distribution, $E_t \sim Normal(0, \sigma^2)$. To estimate the true abundance value, observation errors were added to each X_t:

$$Y_t = X_t + F_t, \tag{3}$$

where Y_t is the estimate of the true abundance value, and F_t is the measurement error with a Gaussian distribution, $F_t \sim Normal(0, \tau^2)$.

Following (Daskalova et al., 2020a, 2020b), we substituted Y_t value into Eq. (2):

$$Y_t = X_{t-1} + \mu + E_t + F_t + F_{t-1}, \tag{4}$$

Eq. (4) is a linear, autoregressive time-series model of order 1 [ARMA (1,1) process] (Dennis et al., 2006, Humbert et al., 2009), and we used a restricted maximum likelihood (REML) approach to estimate the parameters of process error (σ^2), observation or measurement error (τ^2), and the population trends (μ), for each of the time-series.

2.5. Statistical analyses

To quantify the effects of system, taxonomic group, database, data source, and conservation status on population trends, we used a set of multilevel Bayesian models. Multilevel models were used because they can accommodate complex data with a hierarchical structure with both fixed and random effects. In our case, (i) system was a fixed factor with seven levels: freshwater, marine, terrestrial, freshwater/marine, freshwater/terrestrial, marine/terrestrial and freshwater/marine/terrestrial; (ii) taxonomic group was a fixed factor with six levels: amphibians, birds, bony fishes, Elasmobranchii, mammals or reptiles; (iii) database was a fixed factor with two levels: IbeV and LPD; (iv) data source was a fixed factor with three levels: peer-review, grey literature and unknown; (v) protection level of the area was a fixed factor with three levels: protected, unprotected and unknown; and (vi) conservation status was a fixed factor with three levels: threatened, non-threatened and unknown. To account for the non-independence of repeated time-series for each species, we included species name as a random intercept.

The general structure of the models was:

$$P_{OBS,i,j} \sim Normal(P_{TRUE,i,j}, P_{SE,i,j}), \tag{5}$$

$$P_{TRUE,i,j} \sim Normal\left(\mu_{i,j}, \sigma\right), \tag{6}$$

$$\mu_{i,j} = \beta_{0,j}Species + \beta Factor, \tag{7}$$

$$\beta_{0,j}Species \sim Normal(0, 1), \tag{8}$$

$$\beta Factor \sim Normal(0, 1), \tag{9}$$

$$\sigma \sim Exponential(1), \tag{10}$$

where $P_{OBS,i,j}$ represents the distribution of the observed population trends for the time-series i and the species j, which is given by a Normal distribution with mean $P_{TRUE,i,j}$ and variance $P_{SE,i,j}$. $P_{TRUE,i,j}$ represents the true population trend, which is given by a Normal distribution with mean $\mu_{i,j}$ and variance σ. $\beta_{0,j}Species$ represents the intercepts for species, and β the slope. *Factor* represents the system, taxonomic class, database, data source, and conservation status. Also, *Factor* represents the interaction among system and taxa, and the interaction among system, taxa, and data source (to check for the full formulas of the models please check https://github.com/PolCap/iberian_verts). Eq. (7) represents the linear terms of the model. Note that to account for the measurement error derived from the state-space models, we assumed that our data followed a Normal distribution with a mean μ (mean trend from the state-space models) and a variance of σ^2 (the process error from the state-space models).

To check the validity of our multilevel Bayesian models we ran a set of diagnostics. First, we inspected model convergence by visually examining trace plots and using R-hat values (the ratio of the effective sample size to the overall number of iterations, with values close to one indicating convergence; Gelman and Rubin, 1992). Then, we evaluated the model fit by exploring the distribution of the residuals, their variance, and posterior predictive checks (Appendix S7: Figs. S2–S4). In a well-fitted model, the residuals should follow a normal distribution and constant variance (Kruschke, 2014; McElreath, 2020), as shown in our models (Appendix S7: Figs. S2–S3). In addition, the posterior predictive checks compare the distribution of the data with the predictions from the model, so if the model is well-fitted, the predictions should overlap the data, as shown in our models (Appendix S7: Fig. S4).

All models were fitted using the *brms* package v2.1.0 (Bürkner, 2018) in R v4.0.0 (R Core Team, 2020). Models were run for 10,000 iterations, with a warmup of 1000 iterations.

3. Results

3.1. Database description and biases

Our final dataset, including both data from our literature review (IbeV) and data from the Living Planet Database (LDP), resulted in a total of 1543 time-series for 430 vertebrate species, spanning a period from 1927 to 2020. The LDP has 544 time-series of 238 species in the Iberian Peninsula, compared to the 999 time-series of 294 species included in IbeV, with only 102 shared species between the two datasets (Fig. 1a). Therefore, our study contributes to an increase of 183.5713 % in the existing time-series in the LPD. The LPD time-series are dominated by bird (86.6 %) species, with a low proportion of mammals (7.3 %), bony fishes (4.4 %), reptiles (0.7 %) and amphibians (0.4 %; Fig. 1b). The IbeV has a better representation of bony fishes (46.8 %), amphibians (4.5 %), and reptiles (1.2 %), while still having a bias towards mammals (10.4 %) and birds (35.5 %; Fig. 1b). While the LPD is biased towards marine/freshwater/terrestrial (39.5 %), terrestrial (27.2 %), and terrestrial/freshwater (23.3 %) species, the IbeV has a larger representation of marine species (43.5 %; Fig. 1c).While most of the data in the LPD in the Iberian Peninsula comes from grey literature (79.6 %), the information in IbeV includes a relatively balanced share of peer reviewed articles (55.5 %) and grey literature (44.5 %, Fig. 1d). When considering the conservation status of the species included in the databases, both are biased towards non-threatened species (Fig. 1e). This bias is larger for the LPD, with almost 91.7 % of the species being non-threatened, while this value is 71.1 % for the IbeV. Taken together, both datasets cover a large proportion of the Iberian Peninsula, with central areas of Spain and Portugal showing a lower representation (Fig. 2).

3.2. Population trends

Our results show that Iberian vertebrate population trends over time are system- and taxonomic-specific (Fig. 3; Appendix S8: Table S1). The state-space models suggest that 57 % of the populations are increasing over time ($\mu > 0$), whereas 42 % are decreasing ($\mu < 0$) and 1 % are stable ($\mu = 0$). While most mammals and some birds (concretely freshwater/terrestrial and marine/freshwater/terrestrial birds) show signs of population increase (Fig. 3; Appendix S8: Table S1); freshwater and marine/freshwater bony fishes, marine/terrestrial birds and amphibians display negative population trends (Fig. 3; Table S1). These trends are not affected by the length of the time-series, showing no net changes (Appendix S8: Table S2; Fig. S5), nor by the decade of the study (Appendix S8: Table S3; Figs. S6–S7). Moreover, we do not find any differences between populations in protected and unprotected areas (Appendix S8: Fig. S8; Table S4).

Iberian population trends differ across the datasets, conservation status, and data sources (Fig. 4). The two datasets show contrasting overall trends of Iberian vertebrate populations, with the LPD showing a positive trend and IbeV indicating no net change over time (Fig. 4a; Appendix S8: Table S5). All non-threatened species combined show an overall positive trend, while no net change is observed for threatened

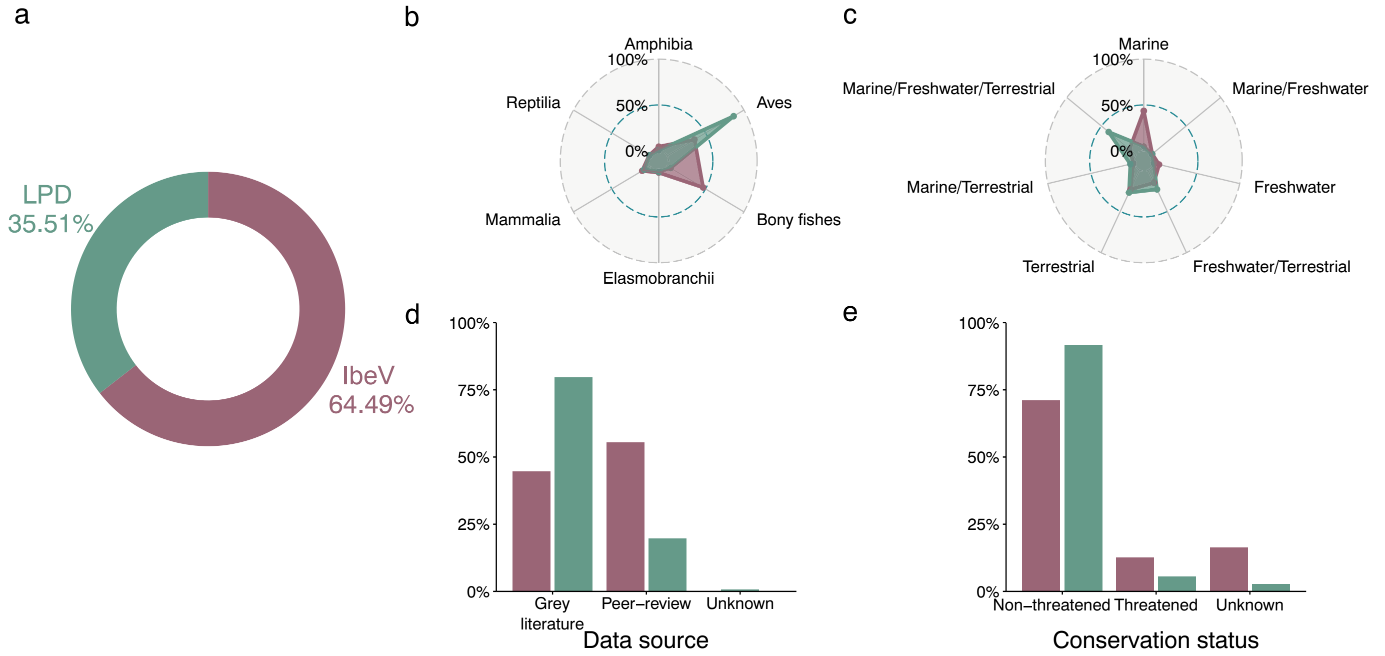

Fig. 1. Overview of the compiled database contents. The database combines data from the Iberian Vertebrate (IbeV) database and the Living Planet Database (LDP), containing 1543 time-series encompassing 430 vertebrate species. We compare IbeV (purplish) and LDP (green) concerning: (a) the general data distribution, (b) across taxonomic groups (c) across systems (d) across data sources and (e) across conservation statuses among species. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

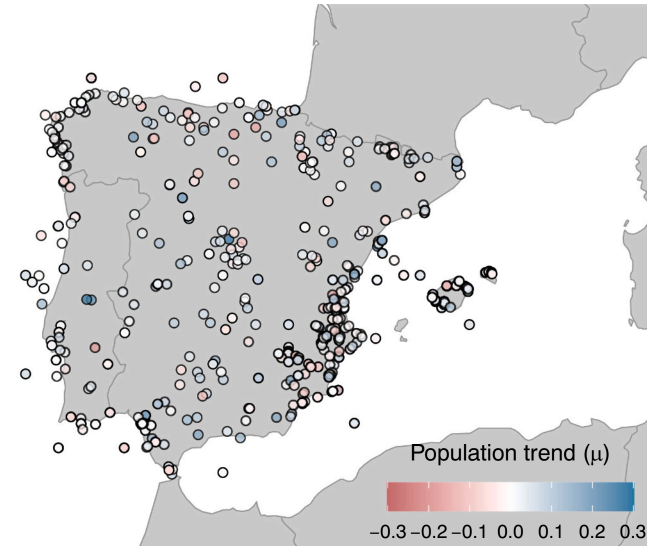

Fig. 2. Map indicating the different vertebrate population time-series included in the compiled dataset. The colour filling each individual dot represents the population trend (μ), where red values indicate population decrease ($\mu < 0$), white values indicate population close to stability ($\mu = 0$), and blue values indicate population increase ($\mu > 0$). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and unknown categories (Fig. 4b; Appendix S8: Table S5). Finally, although both data sources types show positive trends, time-series coming from the grey literature display more positive trends than those from peer-review (Fig. 4c; Appendix S8: Table S5). However, data from unknown sources shows a higher variety of estimates, including both negative and positive trends.

3.3. Differences between IbeV and LPD

Population trends from IbeV differ from LPD ones for some taxonomic groups and systems (Fig. 5). For instance, freshwater/terrestrial and marine/freshwater/terrestrial birds display positive trend in the LPD, while the IbeV displays slightly negative trends (Fig. 5; Appendix S8: Table S6). Similarly, while amphibian and reptiles show slightly positive trends in the LPD, their trends are slightly negative according to the IbeV (Fig. 5; Appendix S8: Table S6). On the contrary, terrestrial birds show negative trends in the LPD, while their trends are slightly positive according to the IbeV (Fig. 5; Table S3). For some other taxonomic groups, population trends are similar, such as in bony fishes, elasmobranchs, or mammals (Fig. 5; Appendix S8: Table S6).

4. Discussion

In this study, we show the importance of including local-level databases for quantifying and assessing temporal biodiversity trends through the compilation of the largest vertebrate population time-series database for the Iberian Peninsula, to date. Our extensive search across the Iberian Peninsula resulted in an almost threefold increase in the number of vertebrate population time-series relative to the LPD. The LPD is one of the largest database of vertebrate population time-series, and it is used to assess the status of wildlife worldwide through the Living Planet Index (LPI) (WWF, 2022). By complementing the LPD data with the Iberian Vertebrates (IbeV) database, we showed that information on population trends can be improved in terms of number of population time-series, and taxonomic and spatio-temporal cover. Moreover, through the compilation of local data, we demonstrate that a local database can display contrasting population trends compared to global databases, such as the LPD (Figs. 4 and 5). Our results, therefore, highlight the relevance of locally-sourced datasets for detecting biodiversity change.

Our results agree with H1 showing a disparity in population trends across taxonomic groups and systems across the two databases. These discrepancies are particularly evident for underrepresented groups in

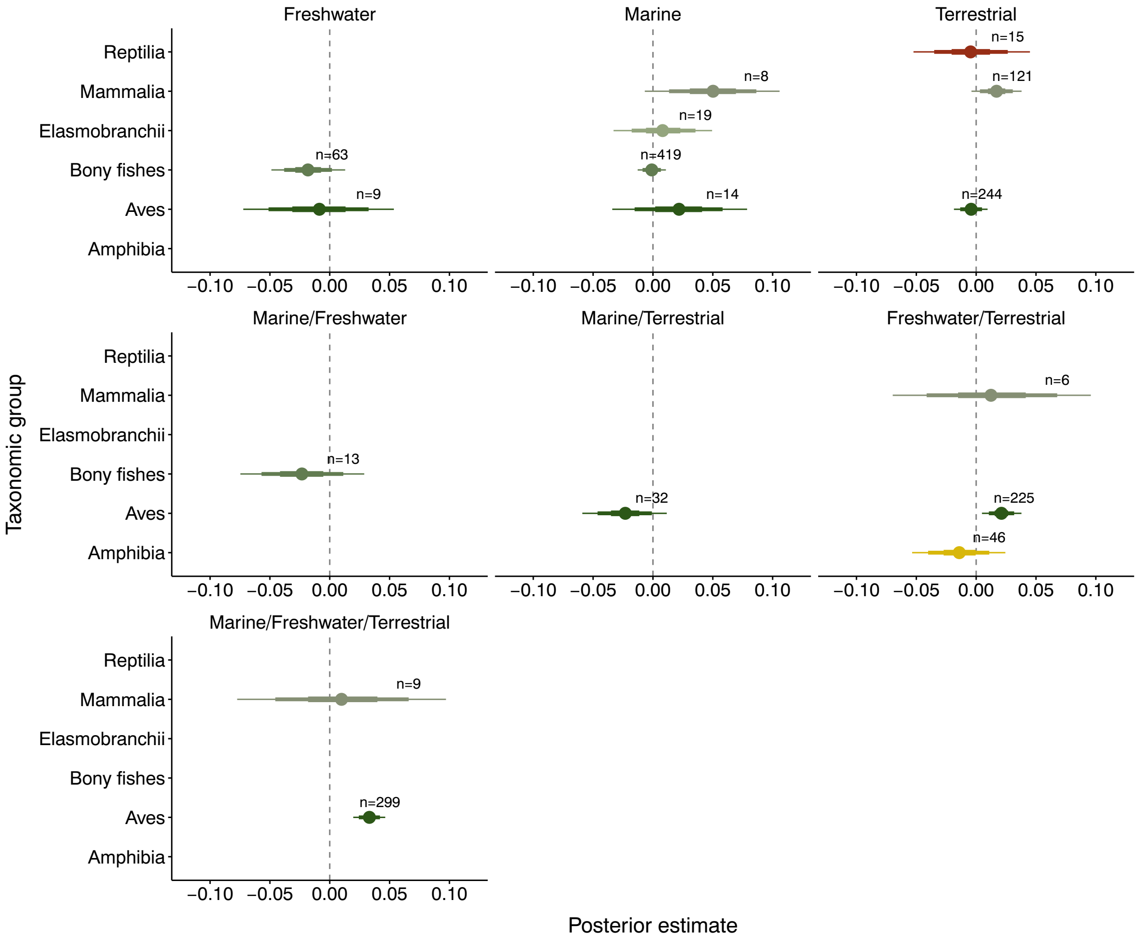

Fig. 3. Vertebrate populations show a wide range of trends across the Iberian Peninsula. 95 % credible intervals of posterior estimates of system and taxonomic group on the 1543 population trends of Iberian vertebrates. The dashed vertical line shows the stable population trend. Different colours represent different taxonomic groups. The credible intervals are based on 1000 samples from the posterior distribution of the slope estimates. Values of n represent the number of time-series per group. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

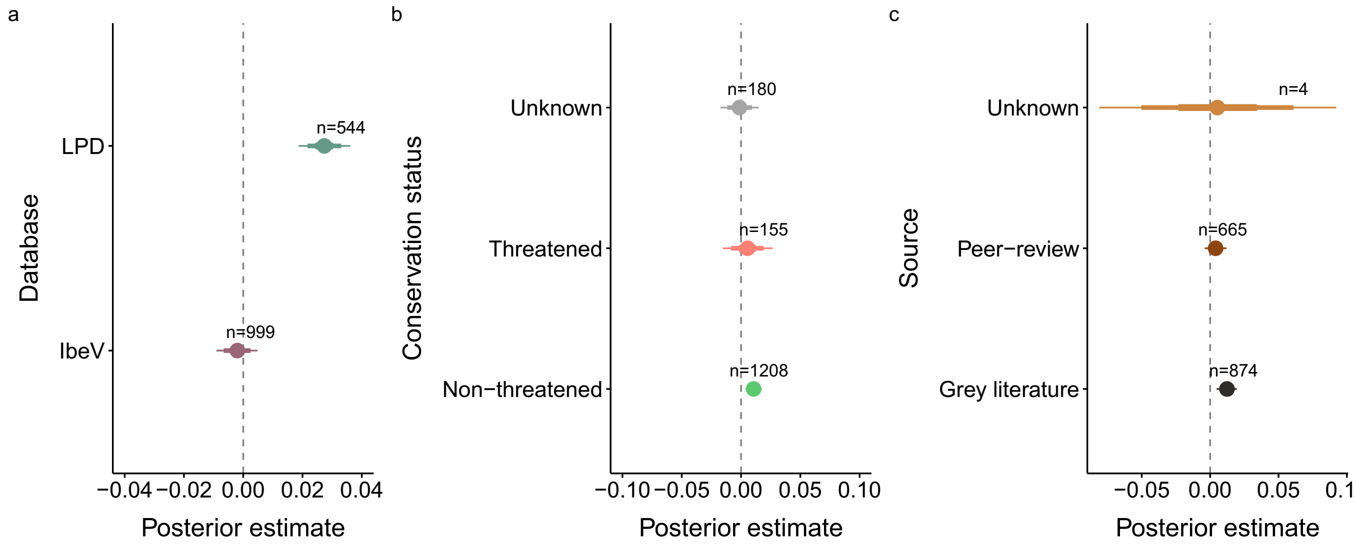

Fig. 4. Vertebrate population trends differ across the databases, conservation statuses, and data sources. 95 % credible intervals in the compiled dataset of (a) the size effects of each database, (b) conservation status according to the IUCN red list, and (c) data source on the 1543 population trends of Iberian vertebrates. The dashed vertical line shows the stable population trend. The credible intervals are based on 1000 samples from the posterior distribution of the slope estimates. Values of n represent the number of time-series per group. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

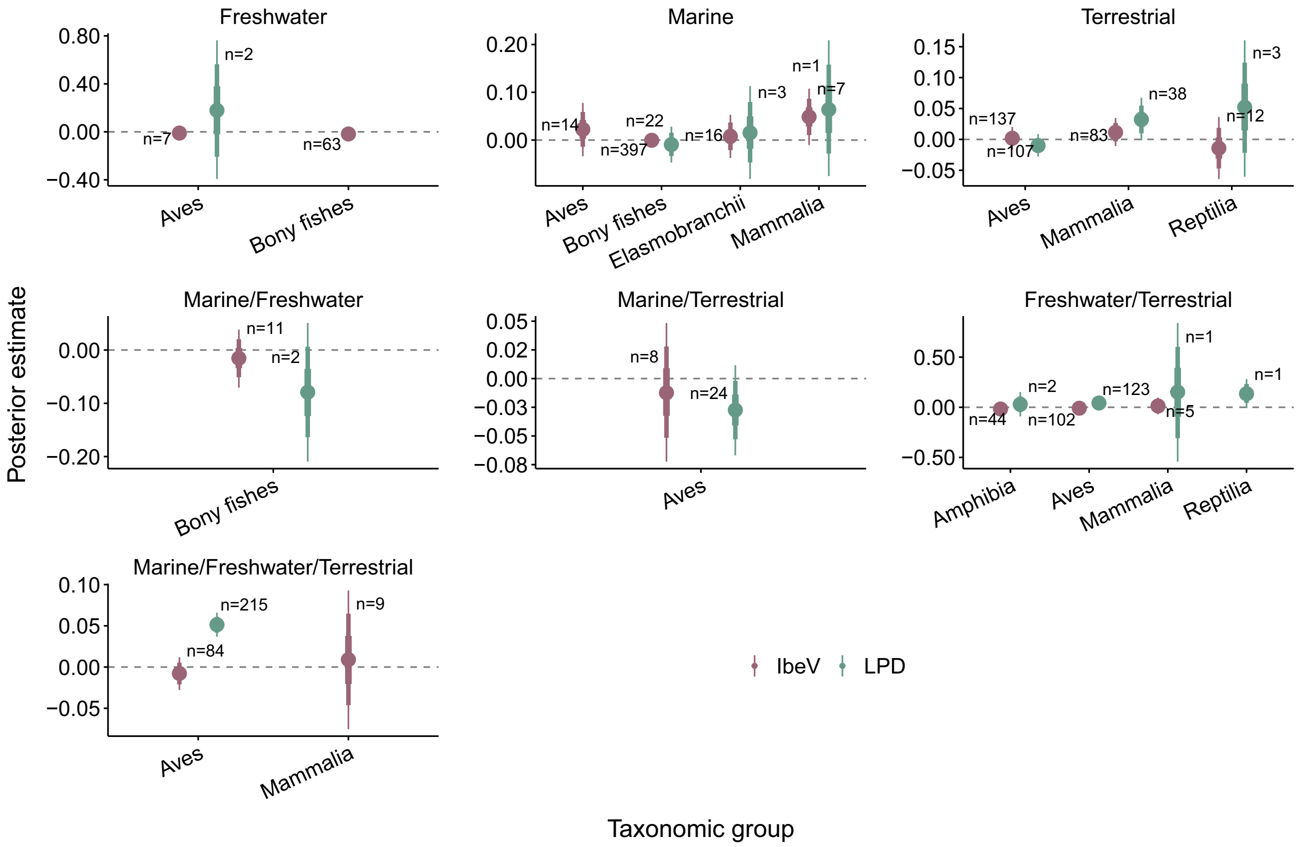

Fig. 5. Iberian vertebrate populations differ according to the data source across different taxonomic groups and systems. 95 % credible intervals of the posterior distribution of data source, system, and taxonomic group on the 1543 population trends of Iberian vertebrates. The dashed horizontal line shows the stable population trend. Colours represent the different database: IbeV (purple) and LDP (green). The credible intervals are based on 1000 samples from the posterior distribution of the slope estimates. Values of n represent the number of time-series per group. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the global databases, such as amphibians and reptiles (Fig. 3). However, both databases show similar trends for several taxonomic groups. For example, bony fishes show population declines, while, in general, mammals show positive trends in all environments. Similarly to other regions worldwide, our results indicate that Iberian amphibians are the taxonomic group experiencing the most pronounced declines (Hoffmann et al., 2010; Leung et al., 2017). On the other hand, we found a positive trend of birds, which contrasts with the negative patterns found in other regions (e.g. Hallmann et al., 2014; Rosenberg et al., 2019; McMahon et al., 2020; Morrison et al., 2021). Regarding systems, we identified that freshwater environments show the greatest decline in population size, in line with global trends (WWF, 2022). For instance, freshwater systems are considered one of the most threatened ecosystems on Earth, due to their prolonged exposure to multiple stressors and/or environmental impacts (Reid et al., 2019). In recent a study, a bias has been described when it comes to conservation efforts and Spanish policies towards mammals and reptiles (García-Macía et al., 2021). These biases in conservation efforts are in line with the results obtained here, where some taxonomic groups (such as mammals and birds) are more studied compared to others (such as reptiles or amphibians). Our local-scale results can be used to evaluate the effects of conservation measures on threatened wildlife by analysing the variations in time-series data from the creation of recovery and conservation plans. With this approach, we can compare time series form species with conservation measures with other species that do not yet have approved plan, because in Spain >80 % of threatened species do not have conservation measures (García-Macía et al., 2021).

We also hypothesized that studies from peer-reviewed articles would show a bias towards reporting declines compared to other sources of information (H2; Donaldson et al., 2016). Nevertheless, we found that datasets coming from peer-reviewed and grey literature showed similar positive population trends. The lack of negative trends in peer-reviewed studies was in line with previous works suggesting no net change in vertebrate population trends at a global scale (Daskalova et al., 2020b). We do note, however, that trends from peer-reviewed manuscripts are more uncertain than those from the grey literature. On the other hand, most of the grey literature data belongs to monitoring programs of vertebrate populations subject to conservation measures, which might create a bias towards positive trends or no net changes. Moreover, the limitations of the temporal spread of the data must also be considered. Although we have not found an influence of the different decades on population trends (Appendix S8: Fig. S6, Table S3), it is important to highlight that most of the concentration of the data is in the decades 1990 and 2000 (Appendix S8: Fig. S9). To obtain diagnoses on a more precise scale, it would be necessary to delve deeper into the effects of temporality in time-series.

We also find that threatened species showed no net change in population trends, whereas non-threatened species have positive trends. This pattern may be influenced by the fact that some IUCN assessments are not up to date, so they do not reflect the population trends that have been estimated based on subsequent studies. For example, the conservation status of the Eurasian Carp, *Cyprinus carpio*, is considered Vulnerable, but some populations show positive trends according to our study. However, its conservation status was updated in the IUCN Red List in 2008 (Freyhof & Kottelat, 2008). In other cases, discrepancies are caused by contrasting populations' trends across regions. For example, threatened species that are in decline across their distribution range, but show no change or increases their Iberian populations. For example, the

Mediterranean populations of the Dusky Grouper, *Epinephelus marginatus*, show positive trends, but the species is decreasing worldwide (IUCN, 2022). In addition, threatened species featured in the studies could be biased towards positive trends because of conservation measures aimed at species recovery. For example, the Iberian lynx, *Lynx pardinus*, has shown positive trends in Spain after the application of several conservation measures (Simon et al., 2012; Garrote et al., 2020).

We show that local population time-series databases improve the capacity to detect signals of population change. Some taxonomic groups, such as some birds, amphibians and reptiles, changed from positive to negative trends when our dataset was used. Such a change on the detection of population trends' signal has important implications for biodiversity research and conservation. First, local databases may contribute to capture clearer patterns of change in local biodiversity than overall global trends. For example, local databases have been instrumental in detecting declines in bird populations across North America (Rosenberg et al., 2019) and shifts in plant diversity in California grasslands (Harrison et al., 2015).

Local databases also allow us to bypass important accessibility barriers to obtain biodiversity data, such as linguistic biases (Amano and Sutherland, 2013; Amano et al., 2021). For instance, our study included a literature search accounting for several official languages in the Iberian Peninsula. Additionally, neglecting locally-sourced data contributes to maintaining existing geographical biases in biodiversity datasets, with the tropics usually being less well represented than temperate areas (Martin et al., 2012; Gonzalez et al., 2016). This perpetuation of biases in biodiversity research has a strong impact in conservation science, given that local and context-dependent evidence is required to inform decision-making and policies (Gutzat and Dormann, 2020). Ignoring these biases can lead to a lack of comprehensive understanding of the actual status of animal populations and ultimately result in less effective or even might mislead management actions (Konno et al., 2020). Accounting for locally sourced data is, therefore, a crucial step to improve our current understanding of biodiversity change.

Although the data obtained in this project almost triples the previous information available, there are still information gaps and biases in some taxonomic groups and systems (H3). Both the LPD and IbeV are strongly biased towards birds, with amphibians, reptiles, and Elasmobranchii being the less studied taxonomic groups. Such biases are concerning, given that these most underrepresented groups are also the most threatened (IUCN, 2022). Although IbeV has a larger absolute number of time-series from these taxonomic groups (e.g., reptiles and amphibians), they still represent <10 % of the time-series in the database. Our data also has important geographical biases within the Iberian Peninsula, with most of the central and less populated areas showing lower coverage. It should also be noted that our study only focused on a small fraction of biodiversity (Bar-On et al., 2018), with other important groups, such as insects or plants, not being considered in the present study. To tackle biodiversity change, there is an urgent need to better understand the trends of these underrepresented taxonomic groups in order to develop effective conservation plans (Trimble and van Aarde, 2012; Troudet et al., 2017). We believe that locally sourced data offers an opportunity to improve this knowledge gap (Troudet et al., 2017).

Amidst the accelerating rate of global change, it is crucial to understand the magnitude of biodiversity change accurately (Díaz et al., 2019; WWF, 2022). To achieve this, it is imperative to effectively measure and track the trends in wild populations across multiple taxonomic groups. However, there are multiple debates regarding the adequacy of available data sets to provide an accurate picture of global biodiversity trends (Gonzalez et al., 2016; Cardinale et al., 2018; Valdez et al., 2023). Our study exemplifies that projects elaborated by local researchers focused on specific regions can improve data coverage and allow for a better understanding of trends. Although, understanding global trends is cornerstone to define global goals for management and environmental policies, the applicability of global datasets can be limiting for understanding more local trends. Therefore, it is important to shift from global to local datasets when management and conservation policies are aimed for smaller spatial scales. Furthermore, global databases can benefit from increased local-level information from local working groups to provide more accurate global estimates. The results of this study are only the first step in the exploration of Iberian faunal trends. It is necessary to go deeper into the processes underlying these patterns, such as the main threats faced by species at the local scale, the differences between functional groups or even the effect of local (national and regional) species conservation policies on population trends.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2024.110755.

CRediT authorship contribution statement

Roberto C. Rodríguez-Caro: Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization. **Zebensui Morales-Reyes:** Writing – review & editing, Validation, Supervision, Investigation, Data curation, Conceptualization. **Alba Aguión:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Rebeca Arias-Real:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Eneko Arrondo:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Eneko Aspillaga:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Jordi Boada:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Andrea Campos-Candela:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Mónica Expósito-Granados:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Aitor Forcada:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Robin Freeman:** Writing – review & editing, Data curation. **Miguel Ángel Gómez-Serrano:** Writing – review & editing, Investigation, Data curation. **Cayetano Gutiérrez-Cánovas:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Roberto Pascual-Rico:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Valentina Marconi:** Writing – review & editing, Investigation, Data curation. **Maria Montseny:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Andreu Rotger:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Graciel·la Rovira:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Amalia Segura:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Iván Sola:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Carlos Valle:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Pol Capdevila:** Writing – review & editing, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors have declared no competing interests.

Data availability

Data will be made available on request.

Acknowledgements

We thank all the public administrations, institutions and researchers that provided us with unpublished databases on vertebrate monitoring programs to incorporate them into this study. The Wildlife and Nature 2000 Service of the Generalitat Valenciana provided access to an important number of time-series of vertebrate data from its monitoring programs in the Valencian Community that began in the 1980s. We would also thank the following institutions for the data sharing: Ministerio para la Transición Ecológica y Reto Demográfico, the regional governments of Andalucia, Aragon and Navarra, the natural parks of

Bardenas Reales de Navarra and Sierras de Cazorla Segura and Villas, the Doñana Biological Station (ICTS-RBD Biodiversity Monitoring Program) and all the member of Nightjaring Group. Some time-series become from el Departamento de Zoología y Antropología Física of the Universidad de Murcia, founded by Fundación Séneca (project 08728/PI/08), and from the Agencia Regional de Ciencia y Tecnología, Región de Murcia; with Life Projecto Segura-Riverlink (project LIFE12 ENV/ES/001140). We also thank to Water Agencies of Spanish surface waters (Basque water agency-URA, Catalan water agency-ACA, CH Cantábrico, CH Duero, CH Ebro, CH Guadalquivir, CH Guadiana, CH Júcar, CH Miño-Sil, CH Segura, CH Tajo. This study was funded by SIBECOL grant "Projects for Early Career Researchers 2020". RCRC was supported by the European Union-Next Generation EU in the Maria Zambrano Program (ZAMBRANO 21-26). ZMR was supported by a postdoctoral contract funded by the Junta de Andalucía (POSTDOC_21_00353). RAR was supported by "Margarita Salas" postdoctoral grant from the Ministerio de Universidades del Gobierno de España and the Next Generation EU – Recovery, Transformation and Resilience Plan. EA was supported by Generalitat Valenciana and European Social Fund (APOSTD/2021), and MCIN/AEI/grant number FJC2021-047885-I. EAs was supported by a ·Vicenç Mut· postdoctoral grant funded by the Department of European Funds, University and Culture of the Govern de les Illes Balears (PD/041/2021). JB acknowledges the support received by the Spanish Ministry of Science and Innovation under the RyC fellowship (RYC2021-033650-I). ACC was founded by the Research Council of Norway (RCN-project nr. 315051). CGC was supported by a Junior Leader Fellowship contract (LCF/BQ/PR22/11920005) funded by "la Caixa" Foundation (ID 100010434). RPR was funded by FJC2020-045938-I/MCIN/AEI/10.13039/501100011033 and European Union "NextGenerationEU"/"PRTR". IS was supported by European Union-Next Generation EU (MARSALAS21-30). The complete list of all authors who contributed information to the manuscript is detailed in Appendix S9.

References

Amano, T., Sutherland, W.J., 2013. Four barriers to the global understanding of biodiversity conservation: wealth, language, geographical location and security. Proc. R. Soc. B Biol. Sci. 280, 20122649.

Amano, T., Berdejo-Espinola, V., Christie, A.P., Willott, K., Akasaka, M., Báldi, A., Berthinussen, A., Bertolino, S., Bladon, A.J., Chen, M., 2021. Tapping into non-English-language science for the conservation of global biodiversity. PLoS Biol. 19, e3001296.

Barnosky, A.D., Matzke, N., Tomiya, S., Wogan, G.O., Swartz, B., Quental, T.B., Marshall, C., McGuire, J.L., Lindsey, E.L., Maguire, K.C., 2011. Has the Earth's sixth mass extinction already arrived? Nature 471, 51–57.

Barnosky, A.D., Hadly, E.A., Bascompte, J., Berlow, E.L., Brown, J.H., Fortelius, M., Getz, W.M., Harte, J., Hastings, A., Marquet, P.A., Martinez, N.D., Mooers, A., Roopnarine, P., Vermeij, G., Williams, J.W., Gillespie, R., Kitzes, J., Marshall, C., Matzke, N., Mindell, D.P., Revilla, E., Smith, A.B., 2012. Approaching a state shift in Earth's biosphere. Nature 486, 52–58.

Bar-On, Y.M., Phillips, R., Milo, R., 2018. The biomass distribution on Earth. Proc. Natl. Acad. Sci. 115 (25), 6506–6511. ISO 690.

Barredo, J.I., Caudullo, G., Dosio, A., 2016. Mediterranean habitat loss under future climate conditions: assessing impacts on the Natura 2000 protected area network. Appl. Geogr. 75, 83–92.

Bowler, D.E., Haase, P., Kröncke, I., Tackenberg, O., Bauer, H.-G., Brendel, C., Brooker, R.W., Gerisch, M., Henle, K., Hickler, T., 2015. A cross-taxon analysis of the impact of climate change on abundance trends in central Europe. Biol. Conserv. 187, 41–50.

Bürkner, P.C., 2018. Advanced Bayesian Multilevel Modeling with the R Package brms. The R Journal 10 (1), 395.

Capdevila, P., Noviello, N., McRae, L., Freeman, R., Clements, C.F., 2022. Global patterns of resilience decline in vertebrate populations. Ecol. Lett. 25, 240–251.

Cardinale, B.J., Gonzalez, A., Allington, G.R.H., Loreau, M., 2018. Is local biodiversity declining or not? A summary of the debate over analysis of species richness time trends. Biol. Conserv. 219, 175–183.

Carmona, C., Tamme, R., Pärtel, M., de Bello, F., Brosse, S., Capdevila, P., Gonzãlez, R., Gonzãlez-Suãrez, M., Salguero-Gãmez, R., Vãsquez-Valderrama, M., Toussaint, A., 2021. Erosion of global functional diversity across the tree of life. Sci. Adv. 7, eabf2675.

Chamberlain, S., 2020. rredlist: "IUCN" Red List Client.

Chamberlain, S.A., Szöcs, E., 2013. taxize: taxonomic search and retrieval in R. F1000Research 2, 191.

Chowdhury, S., Gonzalez, K., Aytekin, M.Ç.K., Baek, S.-Y., Bełcik, M., Bertolino, S., Duijns, S., Han, Y., Jantke, K., Katayose, R., 2022. Growth of non-English-language literature on biodiversity conservation. Conserv. Biol. 36, e13883.

Collen, B.E.N., Loh, J., Whitmee, S., McRae, L., Amin, R., Baillie, J.E., 2009. Monitoring change in vertebrate abundance: the Living Planet Index. Conserv. Biol. 23, 317–327.

Conde, D. A., Staerk, J., Colchero, F., Silva, R. da, Schöley, J., Baden, H. M., Jouvet, L., Fa, J. E., Syed, H., Jongejans, E., Meiri, S., Gaillard, J.-M., Chamberlain, S., Wilcken, J., Jones, O. R., Dahlgren, J. P., Steiner, U. K., Bland, L. M., Gomez-Mestre, I., Lebreton, J.-D., Vargas, J. G., Flesness, N., Canudas-Romo, V., Salguero-Gómez, R., Byers, O., Berg, T. B., Scheuerlein, A., Devillard, S., Schigel, D. S., Ryder, O. A., Possingham, H. P., Baudisch, A. and Vaupel, J. W. 2019. Data gaps and opportunities for comparative and conservation biology. - Proc. Natl. Acad. Sci. 116: 9658–9664.

Daskalova, G.N., Myers-Smith, I.H., Bjorkman, A.D., Blowes, S.A., Supp, S.R., Magurran, A.E., Dornelas, M., 2020a. Landscape-scale forest loss as a catalyst of population and biodiversity change. Science 368, 1341–1347.

Daskalova, G.N., Myers-Smith, I.H., Godlee, J.L., 2020b. Rare and common vertebrates span a wide spectrum of population trends. Nat. Commun. 11, 4394.

Dennis, B., Ponciano, J.M., Lele, S.R., Taper, M.L., Staples, D.F., 2006. Estimating density dependence, process noise, and observation error. Ecol. Monogr. 76, 323–341.

Díaz, S., Settele, J., Brondízio, E.S., Ngo, H.T., Agard, J., Arneth, A., Balvanera, P., Brauman, K.A., Butchart, S.H., Chan, K.M., 2019. Pervasive human-driven decline of life on Earth points to the need for transformative change. Science 366, eaax3100.

Donaldson, M.R., Burnett, N.J., Braun, D.C., Suski, C.D., Hinch, S.G., Cooke, S.J., Kerr, J. T., 2016. Taxonomic Bias and International Biodiversity Conservation Research. Canadian Science Publishing, 65 Auriga Drive, Suite 203, Ottawa, ON K2E 7W6.

Dornelas, M., Gotelli, N.J., Shimadzu, H., Moyes, F., Magurran, A.E., McGill, B.J., 2019. A balance of winners and losers in the Anthropocene. Ecol. Lett. 22, 847–854.

Freyhof, J., Kottelat, M., 2008. Cyprinus carpio. The IUCN Red List of Threatened Species, e.T6181A12559362.

Gamelon, M., Grøtan, V., Nilsson, A.L.K., Engen, S., Hurrell, J.W., Jerstad, K., Phillips, A. S., Røstad, O.W., Slagsvold, T., Walseng, B., Stenseth, N.C., Sæther, B.-E., 2017. Interactions between demography and environmental effects are important determinants of population dynamics. Sci. Adv. 3, e1602298.

García-Macía, J., Pérez, I., Rodríguez-Caro, R.C., 2021. Biases in conservation: a regional analysis of Spanish vertebrates. J. Nat. Conserv. 64, 126094.

Garrabou, J., Gómez-Gras, D., Medrano, A., Cerrano, C., Ponti, M., Schlegel, R., Bensoussan, N., Turicchia, E., Sini, M., Gerovasileiou, V., 2022. Marine heatwaves drive recurrent mass mortalities in the Mediterranean Sea. Glob. Chang. Biol. 28, 5708–5725.

Garrote, G., Fernández-López, J., Rojas, E., López, G., Simón, M.A., 2020. Planning the peninsula-wide recovery of the Iberian lynx: identification of favourable habitat areas. Mammalia 84, 413–420.

Gelman, A., Rubin, D.B., 1992. Inference from iterative simulation using multiple sequences. Stat. Sci. 7, 457–472.

Gómez, A., Lunt, D.H., 2007. Refugia within refugia: patterns of phylogeographic concordance in the Iberian Peninsula. In: Phylogeography of Southern European Refugia. Springer, pp. 155–188.

Gonzalez, A., Cardinale, B.J., Allington, G.R., Byrnes, J., Arthur Endsley, K., Brown, D.G., Hooper, D.U., Isbell, F., O'Connor, M.I., Loreau, M., 2016. Estimating local biodiversity change: a critique of papers claiming no net loss of local diversity. Ecology 97, 1949–1960.

Gutzat, F., Dormann, C.F., 2020. Exploration of concerns about the evidence-based guideline approach in conservation management: hints from medical practice. Environ. Manag. 66, 435–449.

Hallmann, C.A., Foppen, R.P., van Turnhout, C.A., de Kroon, H., Jongejans, E., 2014. Declines in insectivorous birds are associated with high neonicotinoid concentrations. Nature 511, 341–343.

Harrison, S.P., Gornish, E.S., Copeland, S., 2015. Climate-driven diversity loss in a grassland community. Proc. Natl. Acad. Sci. 112, 8672–8677.

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T.M., Butchart, S.H., Carpenter, K.E., Chanson, J., Collen, B., Cox, N.A., 2010. The impact of conservation on the status of the world's vertebrates. Science 330, 1503–1509.

Humbert, J.-Y., Scott Mills, L., Horne, J.S., Dennis, B., 2009. A better way to estimate population trends. Oikos 118, 1940–1946.

IUCN, 2022. The IUCN Red List of threatened species. Version 2022-1. https://www.iucnredlist.org.

Khaliq, I., Fritz, S.A., Prinzinger, R., Pfenninger, M., Böhning-Gaese, K., Hof, C., 2015. Global variation in thermal physiology of birds and mammals: evidence for phylogenetic niche conservatism only in the tropics. J. Biogeogr. 42, 2187–2196.

Konno, K., Akasaka, M., Koshida, C., Katayama, N., Osada, N., Spake, R., Amano, T., 2020. Ignoring non-English-language studies may bias ecological meta-analyses. Ecol. Evol. 10, 6373–6384.

Kruschke, J., 2014. Doing Bayesian Data Analysis: A Tutorial With R, JAGS, and Stan (in press).

Leung, B., Greenberg, D.A., Green, D.M., 2017. Trends in mean growth and stability in temperate vertebrate populations. Divers. Distrib. 23, 1372–1380.

Leung, B., Hargreaves, A.L., Greenberg, D.A., McGill, B., Dornelas, M., Freeman, R., 2020. Clustered versus catastrophic global vertebrate declines. Nature 588, 267–271.

Loh, J., Green, R.E., Ricketts, T., Lamoreux, J., Jenkins, M., Kapos, V., Randers, J., 2005. The Living Planet Index: using species population time series to track trends in biodiversity. Philos. Trans. R. Soc. B Biol. Sci. 360, 289–295.

Martin, L.J., Blossey, B., Ellis, E., 2012. Mapping where ecologists work: biases in the global distribution of terrestrial ecological observations. Front. Ecol. Environ. 10, 195–201.

Martín-Forés, I., Martín-López, B., Montes, C., 2013. Anthropomorphic factors influencing Spanish conservation policies of vertebrates. Int. J. Biodivers. 2013 (1), 142670.

Martín-López, B., Montes, C., Ramírez, L., Benayas, J., 2009. What drives policy decision-making related to species conservation? Biol. Conserv. 142, 1370–1380.

Martín-López, B., González, J.A., Montes, C., 2011. The pitfall-trap of species conservation priority setting. Biodivers. Conserv. 20, 663–682.

Martins, I.S., Proença, V., Pereira, H.M., 2014. The unusual suspect: land use is a key predictor of biodiversity patterns in the Iberian Peninsula. Acta Oecol. 61, 41–50.

McElreath, R., 2020. Statistical Rethinking: A Bayesian Course With Examples in R and Stan. CRC press.

McGill, B.J., Dornelas, M., Gotelli, N.J., Magurran, A.E., 2015. Fifteen forms of biodiversity trend in the Anthropocene. Trends Ecol. Evol. 30 (2), 104–113.

McMahon, B.J., Doyle, S., Gray, A., Kelly, S.B., 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.

Morrison, C.A., Auniņš, A., Benkő, Z., Brotons, L., Chodkiewicz, T., Chylarecki, P., Escandell, V., Eskildsen, D.P., Gamero, A., Herrando, S., 2021. Bird population declines and species turnover are changing the acoustic properties of spring soundscapes. Nat. Commun. 12, 6217.

Murali, G., de Oliveira Caetano, G.H., Barki, G., Meiri, S., Roll, U., 2022. Emphasizing declining populations in the Living Planet Report. Nature 601, E20–E24.

Pick, J.L., Nakagawa, S., Noble, D.W., 2019. Reproducible, flexible and high-throughput data extraction from primary literature: the metaDigitise r package. Methods Ecol. Evol. 10, 426–431.

Pullin, A.S., Knight, T.M., 2009. Data credibility: a perspective from systematic reviews in environmental management. N. Dir. Eval. 2009, 65–74.

R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Ramo, C., Aguilera, E., Figuerola, J., Máñez, M., Green, A.J., 2013. Long-term population trends of colonial wading birds breeding in Doñana (SW Spain) in relation to environmental and anthropogenic factors. Ardeola 60, 305–326.

Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T., Kidd, K.A., MacCormack, T.J., Olden, J.D., Ormerod, S.J., 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biol. Rev. 94, 849–873.

Rendón, M.A., Green, A.J., Aguilera, E., Almaraz, P., 2008. Status, distribution and long-term changes in the waterbird community wintering in Doñana, south–west Spain. Biol. Conserv. 141, 1371–1388.

Rodríguez-Caro, R.C., Lima, M., Anadón, J.D., Graciá, E., Giménez, A., 2016. Density dependence, climate and fires determine population fluctuations of the spur-thighed tortoise Testudo graeca. J. Zool. 300, 265–273.

Rosenberg, K.V., Dokter, A.M., Blancher, P.J., Sauer, J.R., Smith, A.C., Smith, P.A., Stanton, J.C., Panjabi, A., Helft, L., Parr, M., 2019. Decline of the North American avifauna. Science 366, 120–124.

Simon, M.A., Gil-Sanchez, J.M., Ruiz, G., Garrote, G., Mccain, E.B., Fernandez, L., Lopez-Parra, M., Rojas, E., Arenas-Rojas, R., Del Rey, T., 2012. Reverse of the decline of the endangered Iberian lynx. Conserv. Biol. 26, 731–736.

Sola, I., Fernández-Torquemada, Y., Forcada, A., Valle, C., del Pilar-Ruso, Y., González-Correa, J.M., Sánchez-Lizaso, J.L., 2020. Sustainable desalination: long-term monitoring of brine discharge in the marine environment. Mar. Pollut. Bull. 161, 111813 https://doi.org/10.1016/j.marpolbul.2020.111813.

Stewart-Oaten, A., Murdoch, W.W., Parker, K.R., 1986. Environmental impact assessment: “pseudoreplication” in time? Ecology 67, 929–940. https://doi.org/10.2307/1939815.

Trimble, M.J., van Aarde, R.J., 2012. Geographical and taxonomic biases in research on biodiversity in human-modified landscapes. Ecosphere 3, art119.

Troudet, J., Grandcolas, P., Blin, A., Vignes-Lebbe, R., Legendre, F., 2017. Taxonomic bias in biodiversity data and societal preferences. Sci. Rep. 7, 1–14.

Valdez, J.W., Callaghan, C.T., Junker, J., Purvis, A., Hill, S.L.L., Pereira, H.M., 2023. The undetectability of global biodiversity trends using local species richness. Ecography 2023, e06604.

van Strien, A.J., Meyling, A.W.G., Herder, J.E., Hollander, H., Kalkman, V.J., Poot, M.J., Turnhout, S., van der Hoorn, B., van Strien-van Liempt, W.T., van Swaay, C.A., 2016. Modest recovery of biodiversity in a western European country: the Living Planet Index for the Netherlands. Biol. Conserv. 200, 44–50.

WWF, 2022. In: Almond, R.E.A., Grooten, M., Juffe Bignoli, D., Petersen, T. (Eds.), Living Planet Report 2022 – Building a Naturepositive Society. WWF, Gland, Switzerland.