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CONTRIBUTED PAPER

Changes in community composition and functional diversity of European bats under climate change

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Article impact statement: Climate change reshapes European bat communities and their functional diversity, which has implications for their conservation in Europe.

Abstract

Climate change is predicted to drive geographical range shifts that will result in changes in species diversity and functional composition and have potential repercussions for ecosystem functioning. However, the effect of these changes on species composition and functional diversity (FD) remains unclear, especially for mammals, specifically bats. We used species distribution models and a comprehensive ecological and morphometrical trait database to estimate how projected future climate and land-use changes could influence the distribution, composition, and FD of the European bat community. Future bat assem-

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blages were predicted to undergo substantial shifts in geographic range and trait structure. Range suitability decreased substantially in southern Europe and increased in northern latitudes. Our findings highlight the potential for climate change to drive shifts in bat FD, which has implications for ecosystem function and resilience at a continental scale. It is important to incorporate FD in conservation strategies. These efforts should target species with key functional traits predicted to be lost and areas expected to experience losses in FD. Conservation strategies should include habitat and roost protection, enhancing landscape connectivity, and international monitoring to preserve bat populations and their ecosystem services.

KEYWORDS
bats, community composition, functional composition, global change, species distribution modeling

INTRODUCTION

Climate change is a key and growing threat to biodiversity (IPCC, 2022) that is driving substantial shifts in patterns of species distribution and diversity worldwide (Chen et al., 2011; Parmesan & Yohe, 2003; Walther et al., 2002). Under future climate change scenarios, the geographic range for many species is predicted to expand or contract in size or shift along latitudinal and elevational gradients (Dullinger et al., 2012; Rebelo et al., 2010; Thomas et al., 2004). The variation in species-specific responses to climate change can lead to the emergence of new species assemblages differing in compositions and functions from those observed today (Williams & Jackson, 2007). Such changes can influence biotic interactions (Blois et al., 2013), alter ecosystem processes (Loreau et al., 2001), and possibly trigger trophic cascades (Mäntylä et al., 2011). The impacts of climate change on species distributions will be exacerbated by ongoing anthropogenic land-use change in the form of habitat loss and fragmentation, which is already responsible for an extensive decline in wildlife abundance and functional diversity (FD) across the globe (Brodie et al., 2021; Maxwell et al., 2016). Such land-use changes are also likely to impair species' ability to shift their ranges in response to future climate change (Robillard et al., 2015).

Species distributional changes have consequences at the community level. Competition may emerge when newly arriving species use the same limited resources that local species rely on (e.g., Tannerfeldt et al., 2002). If generalist species colonize areas that have become climatically suitable for them, they may displace local, more habitat specialists, as seen in small mammal assemblages at high elevations (Clavel et al., 2011; Rowe et al., 2010). Thus, climate-change-induced distributional shifts can lead to a simplification of communities as opportunistic species expand to new areas, and specialist species may experience range contractions and ultimately disappear (McKinney & Lockwood, 1999). These changes could have further repercussions on ecosystem functions due to shifts in functional composition (Thuiller et al., 2006). Replacing local species with functionally different species (Rosenfeld, 2002) can have substantial and potentially unpredictable impacts on community structure and ecosystem functioning. Furthermore, climate-change-induced range shifts in mammals can lead to an increase in cross-species transmission of pathogens, which can affect population viability (Carlson et al., 2022). Hence, understanding and assessing such changes in range, assemblage structure, and FD is an important step toward developing effective conservation strategies, particularly in regions where ecosystem functions are likely to be affected by climate change (McCarthy et al., 2011; Roy et al., 2015).

Bats offer an important case study for community-level responses to climate change due to their high diversity, distinct ecological roles, and sensitivity to environmental changes. Bats, accounting for 20% of mammalian species, are widely distributed and play key ecological roles, such as insect suppression (Jones et al., 2009; Kunz et al., 2011). Bats are thought to be particularly sensitive to climate change, especially to temperature increases and extreme events, because their high body surface-to-volume ratios due to large wing and tail membranes mean they are prone to dehydration (Korine et al., 2016). Changing temperatures can affect various aspects of bat physiology and ecology, from torpor duration and intensity to reproduction requirements and food availability, which can lead to demographic and spatial responses to climate change (reviewed in Festa et al. [2022] and Sherwin et al. [2013]). Conversely, due to their flight ability, some bat species have a greater capacity for long-distance dispersal (Hutterer et al., 2005) relative to small terrestrial mammals (e.g., rodents and shrews) and consequently higher range shift potential in the face of climate change, assuming the availability of habitats.

Numerous studies have demonstrated the impact of climate change on the distribution, activity, survival, and reproductive success of bats. Yet, impacts at the community and functional level have not been explored (Festa et al., 2022). To address this knowledge gap, we predicted how projected future climate and land-use changes may influence the distribution, composition, and FD of the European bat community. To this end, we collected a unique data set of more than 14,000 observations through a cross-European collaborative network and employed ensemble forecasting to predict the future range suitability for 37 European bat species. We integrated these predictions with species traits to estimate future trajectories in community composition and FD. We hypothesized that climatic suitability increases in northern Europe and decreases in southern Europe, resulting in a shift in patterns of species richness, and that shifts

in climatic suitability across Europe lead to changes in community composition and FD in northern and southern latitudes. We predicted that gains in species richness in northern Europe will result in more pronounced changes in community composition and FD than range losses in southern Europe because there are fewer species in northern Europe.

METHODS

Study area

The study area encompassed Europe and the North African and Middle Eastern regions bordering the Mediterranean Sea (Appendix S1). We extended the study area to North Africa and the Middle East to include the southern range limits of the distribution of some European bat species (e.g., *Pipistrellus kuhlii*, *Rhinolophus mehelyi*, *Barbastella barbastellus*) and hence capture their full range of climatic tolerances. This area covered the geographic range of the most common European species and the European near-endemic bat species (Hackländer & Zachos, 2020). We included only European bat species because of a lack of information on non-European species for assessing changes in FD.

Bat species occurrence data

We collected a comprehensive data set of unpublished location records from bat experts from across Europe through the ClimBats COST Action network (CA18107). We obtained data from 66 data providers for 29 countries, including location records from 1980. We supplemented our data set with location records extracted from the literature for North Africa (Appendix S2) and the EUROBATS data set (www.eurobats.org). We did not use GBIF records because of concerns about their accuracy with cryptic species identification and their associated spatial bias (Beck et al., 2014). This approach ensured our data set was robust and reliable and avoided potential pitfalls associated with commonly used databases.

We removed duplicate records and thinned the records of each species to 40 km with the R package spThin (Aiello-Lammens et al., 2015) to reduce spatial clustering. This value resulted in the best balance between retaining a sufficient number of records and reducing clustering in more densely sampled countries. The final data set included 14,638 location records of 37 bat species. Species presence data ranged between 62 locations for *Plecotus kolombatovici* and 929 for *Pipistrellus pipistrellus* (average 393.05 location records [SD 234.58]) (Appendix S3). These data are available from Dryad https://doi.org/10.5061/dryad.2z34tmpx6.

Environmental variables

We selected 8 environmental variables that are ecologically meaningful for bats and likely to limit their distribution, based on knowledge of the ecology of European bats (Table 1). We combined climatic, land cover, and topographic variables. We initially included 6 bioclimatic variables downloaded from CHELSA-Climate (Karger et al., 2017) at a 30-arc-second resolution (~1 km), 2 land cover variables, proportion of forested and urban area derived from the 300-m-resolution Globio4 map (Schipper et al., 2020), and one topographic variable, which was calculated from the Copernicus Digital Elevation Model data set at a 30-m resolution (topographic ruggedness index) (Appendix S4). We used the R package raster (Hijmans et al., 2015) to upscale variables to approximately 5 km, corresponding to the average home range of bat species (Stebbings & Griffith, 1986), and thus include the area likely used by the bat around each location record. We removed intercorrelated variables with variation inflation factor >10 and Spearman correlation rho $>|0.7|$. The final data set included 5 bioclimatic variables, 2 land cover variables, and one topographic variable (Table 1).

TABLE 1 Environmental variables used for European bat species distribution modeling.

Variable abbreviation	Description
CHELSA Bio04	Temperature seasonality
CHELSA Bio05	Maximum temperature of warmest month
CHELSA Bio12	Annual precipitation
CHELSA Bio15	Precipitation seasonality
CHELSA bio18	Precipitation of warmest quarter
Globio forested	Land cover—forest
Globio urban	Land cover—urban
DEM ruggedness	Topographic ruggedness index

To forecast species distribution under future scenarios, we used projected climatic data for 2041–2060 based on the RCP 4.5 (representative concentration pathway) and RCP 8.5 scenarios (medium- and high-emission scenarios) (IPCC, 2022) and 3 general circulation models (HadGEM2, IPSL-CM5A, and MPI-ESM) (www.chelsa-climate.org) chosen because of their European focus (IPCC, 2013). Future land cover projections were based on the Globio4 model and the SSP3 and SSP5 scenarios (Schipper et al., 2020). We focused on the results of the high-emission scenarios (RCP 8.5 and SSP5) to highlight the consequences of inaction on climate change.

Modeling procedure

We generated species distribution models (SDMs) to predict the impact of climate change on the ranges of 37 bat species across the study area. For each species, occurrence records were split into 70% training and 30% testing data. For each species range, we generated 10,000 random background points with the dismo package (Hijmans et al., 2017). Following best practices (Araújo et al., 2019), SDMs were fitted using an ensemble approach with 4 different algorithms: generalized additive models (McCullagh & Nelder, 1989), boosted regression trees (Elith et al., 2008),

artificial neural networks (Lek & Guégan, 1999), and maximum entropy (Phillips et al., 2006). We used the R package biomod2 4.1.2 (Thuiller et al., 2016) to generate the models. We adjusted the model parameters of each algorithm for each species with SDMtune (Vignali et al., 2020) to improve model performance (Merow et al., 2013) (Appendix S5).

We used the true skill statistics (TSS) and the area under the curve (AUC) of the receiver operating characteristic to evaluate model performance. We employed random cross-validation to estimate the binary threshold for predictions and then assessed the model's performance with geographic block cross-validation with the R package blockCV (Valavi et al., 2019). We combined the models generated from different algorithms into an ensemble model by averaging their outputs, weighing each model's contribution based on its AUC and TSS scores, and excluding models with low discrimination ability (AUC $<$ 0.75 and TSS $<$ 0.5). Final individual models were then run with all location records. Continuous predictions of the single models were then converted to binary presence–absence maps with the approach that maximizes the sum of model sensitivity and specificity (Liu et al., 2013).

We projected our models to 2041–2060 with the RCP 8.5 and RCP 4.5 emission scenarios and the 3 General Circulation Models (GCMs). We combined the outputs of models generated with the mean of the 3 GCMs. We calculated the extent of changes in range suitability between present and future conditions in biomod2 by overlapping the binary present and future model output maps for each bat species and calculating actual and percent changes in predicted range size (number of cells). Subsequently, the binary maps for each bat species were added to produce species richness maps, which we used to calculate changes in diversity under future climate change at each raster cell.

We ran a multivariate environmental similarity surfaces (MESS) analysis, as recommended by Elith et al. (2010), across the whole of Europe and North Africa to determine whether our study area was predicted to be in nonanalog condition. The MESS plots showed that all variables were within the range present in the training (current) data across Europe, with the exception of Bio4 in parts of Ukraine and Russia and Bio5 in the Sahara (Appendix S6). Neither of these areas was included in our projected models and subsequent analyses.

Community-level and FD analyses

To determine how climate change will affect bat community composition, we calculated beta diversity with the Jaccard dissimilarity index between present and future predictions at a 50-km resolution. To compute the Jaccard dissimilarity index, we used the predicted presence and relative occupancy of species within each grid cell. The relative occupancy of species was calculated based on the proportion of the 50-km cell predicted to be occupied by the species. We partitioned beta diversity into community turnover and nestedness in the betapart R package 1.6 (Baselga & Orme, 2012). This partition allows us to discriminate between community changes due to species substitutions (turnover) and community changes due to the loss of existing species (nestedness).

To assess the effects of climate change on FD, we assembled morphological and ecological trait data from a comprehensive data set for European bat traits (EuroBaTrait 1) (Froidevaux et al., 2023) that provides information on key dimensions of the bat niche and ecological attributes. We initially selected 13 key traits that are important for characterizing bats and have good coverage across the studied species. After removing highly correlated traits, the following 10 traits were retained: home range (area used to satisfy daily needs, representing movement behavior), estimated extent of occurrence (range size, representing extinction risk due to restricted geographic distribution), upper elevation limit, dietary diversity, dietary specialization index (range from specialists to generalists), body mass (influencing metabolic rate, energy demand, and diet), aspect ratio index (measure of wing morphology, relates to movement and dispersal behavior), echolocation call peak frequency (relates to foraging behavior and habitat use), foraging habitat selection, and thermal index (average temperatures across the species' range) (trait descriptions and how they were measured are in Appendix S7). These traits relate to species foraging and movement ability, environmental tolerance, and energy demand and consumption and therefore represent how a given organism affects the community structure and species interaction network, with potential consequences for ecosystem functioning (Thévenin et al., 2022).

Because 10 of the 13 functional traits had missing data for some species (mean = 9.7 species, range 2–21, corresponding to a mean = 26.2%, range 5.4–56.7% of the total), we filled data gaps through imputation with missForest imputation (Stekhoven & Bühlmann, 2012; Stewart et al., 2023). missForest uses a random forest approach to impute missing values and effectively captures complex relationships among continuous and categorical variables. Previous comparative analyses have demonstrated good imputation performance (Penone et al., 2014). We included phylogenetic eigenvectors in the imputation by conducting a principal components analysis (PCA) on pairwise phylogenetic distances among species. The first 10 phylogenetic eigenvectors were used as predictor variables in the missForest imputation procedure, following Penone et al. (2014), alongside functional traits. Errors were assessed using the normalized root mean squared error (NRMSE):

$$\text{NRMSE} = 100 \times \text{RMSE}/\text{range of the original variable}. \quad (1)$$

The imputation resulted in relatively low errors, which were deemed acceptable for the purpose of our analyses. The average NRMSE for the imputed values was 19.7% (range 14.4–25.1%).

Then, we used the predicted species presence and relative occupancy per 50-km cell to calculate FD for the 2 time periods with the FD R package 1.0 (Laliberté et al., 2014). We used the functional dispersion metric, which represents the average distance of individual species to the weighted centroid of all species within a multidimensional trait space (Laliberte & Leg-

endre, 2010). As for beta diversity, the weighting of functional dispersion was obtained using the predicted relative occupancy of species per grid cell with the SDM binary outputs.

We calculated the difference between present and future estimates of the FD metrics. To assess geographic patterns of trait distributions and predict their changes over time, we also estimated the community-weighted mean (CWM) of each trait value per cell and measured its difference between the 2 time steps. The CWM is measured as the mean trait value for all species in the community, weighted by species relative abundance (in this case, their relative occupancy per 50-km grid cell). We then explored each trait visually to identify changes in each trait.

To estimate the contribution of individual species' range changes to the predicted change in functional dispersion, we fitted a random forest model. We used the predicted change in species occupancy per cell as a predictor variable and the predicted change in functional dispersion as the response variable. We fitted 1000 random trees and varied the number of variables randomly sampled as candidates at each split between 6 and 20. We selected 12 as the value resulting in the minimum error estimate.

RESULTS

Species distribution model performance and current patterns of range suitability

The average performance of the 4 algorithms was good (0.8) to excellent (>0.9), as indicated by the relatively high cross-validation data mean AUC scores (full model: AUC = 0.905 [SD 0.037], range 0.831–0.971; Area Under the Curve cross-validation (AUCcv) = 0.871 [0.016], range 0.798–0.9559) and TSS scores (full model: 0.720 [0.985], range 0.578–0.931; TSS cross-validation 0.593 [0.037], range 0.383–0.819). Although the contribution of predictor variables in the model varied among species, overall, climatic variables contributed the most to the models of all bat species. The maximum temperature of the warmest month (BIO05) had the highest contribution (Appendix S8).

Future projections

Under future conditions (RCP 8.5), most European bat species were projected to experience range losses due to climate change (Figure 1). Projected range changes were more moderate under the moderate-emission scenario (RCP 4.5) but followed very similar patterns (Appendix S9). Of the 37 modeled bat species, 7 were predicted to experience severe range contractions of >30% by 2050. The greatest losses of range were predicted for *Myotis dasycneme* (∼70%), followed by *R. mehelyi* (∼50%). Only one of the 37 European bat species, *Pipistrellus nathusii*, was predicted to experience range gains of approximately 21% under future climate change scenarios. *Nyctalus noctula*, *Plecotus auritus*, and *Plecotus austriacus* were predicted overall to experience small net changes in the extent of their range under climate change. Nonetheless, under climate change, the ranges of all 4 species were predicted to shift to higher latitudes. These range shifts were characterized by southern European range reductions and northern European gains. The ranges of the remaining 5 species, *Eptesicus isabellinus*, *Myotis capaccinii*, *Myotis crypticus*, *Tadarida teniotis*, and *Plecotus macrobullaris*, were predicted to contract by 30–45% (Figure 1; see https://doi.org/10.5061/dryad.2z34tmpx6 for details).

Community turnover, species richness, and FD

Models for all 37 European bat species predicted range losses primarily in southern Europe, where the greatest number of species is currently found (up to 33 modeled species), and gains in northern latitudes. These shifts in geographical distributions altered patterns of diversity and community composition across Europe. Our models predicted an increase in species richness in Ireland, western Britain, and central and northern Europe. Many parts of southern Europe, such as the Iberian Peninsula, were predicted to experience a high negative turnover for the modeled species (Figure 2). Considerable losses in geographic range were predicted in southern Spain and the Mediterranean islands for some species, such as *E. isabellinus*, *P. pipistrellus*, and *Pipistrellus pygmaeus*.

Functional diversity followed a spatial pattern similar to that of community turnover; FD changes (gains and losses) were heterogeneous. Models projected large increases in FD in northern latitudes, especially in Norway, northern Sweden, and Finland (Figure 3). These increases aligned closely with substantial range shifts of, for example, *Myotis brandtii* and *Myotis mystacinus* to these higher latitudes (Figure 4). In contrast, certain areas in southern Sweden and Finland were predicted to experience a reduction in FD, despite an increase in species richness (Figure 2). These changes were primarily attributed to the loss of morphologically distinct species, such as *Eptesicus nilssonii* (Figure 4). In contrast, Eastern Europe, eastern England, and parts of southern Spain were predicted to face decreases in FD for the modeled species (Figure 3). These decreases were associated with range losses of *Vespertilio murinus*, *N. noctula*, and *M. mystacinus* (Figure 4).

The best-supported model for the contribution of individual species range changes to the predicted change in functional dispersion explained 64.83% of the variance. The most important species driving the change in functional dispersion were *E. nilssonii* and *M. brandtii*, followed by *M. daubentonii*, *Rhinolophus hipposideros*, *V. murinus*, *N. noctula*, *P. kuhlii*, *M. dasycneme*, and *E. serotinus*. *Myotis mystacinus* also contributed, but to a lesser extent (Appendix S10).

Maps of changes in each functional trait showed that the increase in FD across Fennoscandia was driven primarily by dietary traits, whereby diet diversity increased, while diet specialization decreased. We found an opposite trend in Eastern Europe, eastern Britain, Italy, and southern Spain, where the same dietary diversity trait decreased, resulting in a reduced FD (Figure 5). For the Fennoscandian region, the FD increase was also closely associated with body mass and thermal index

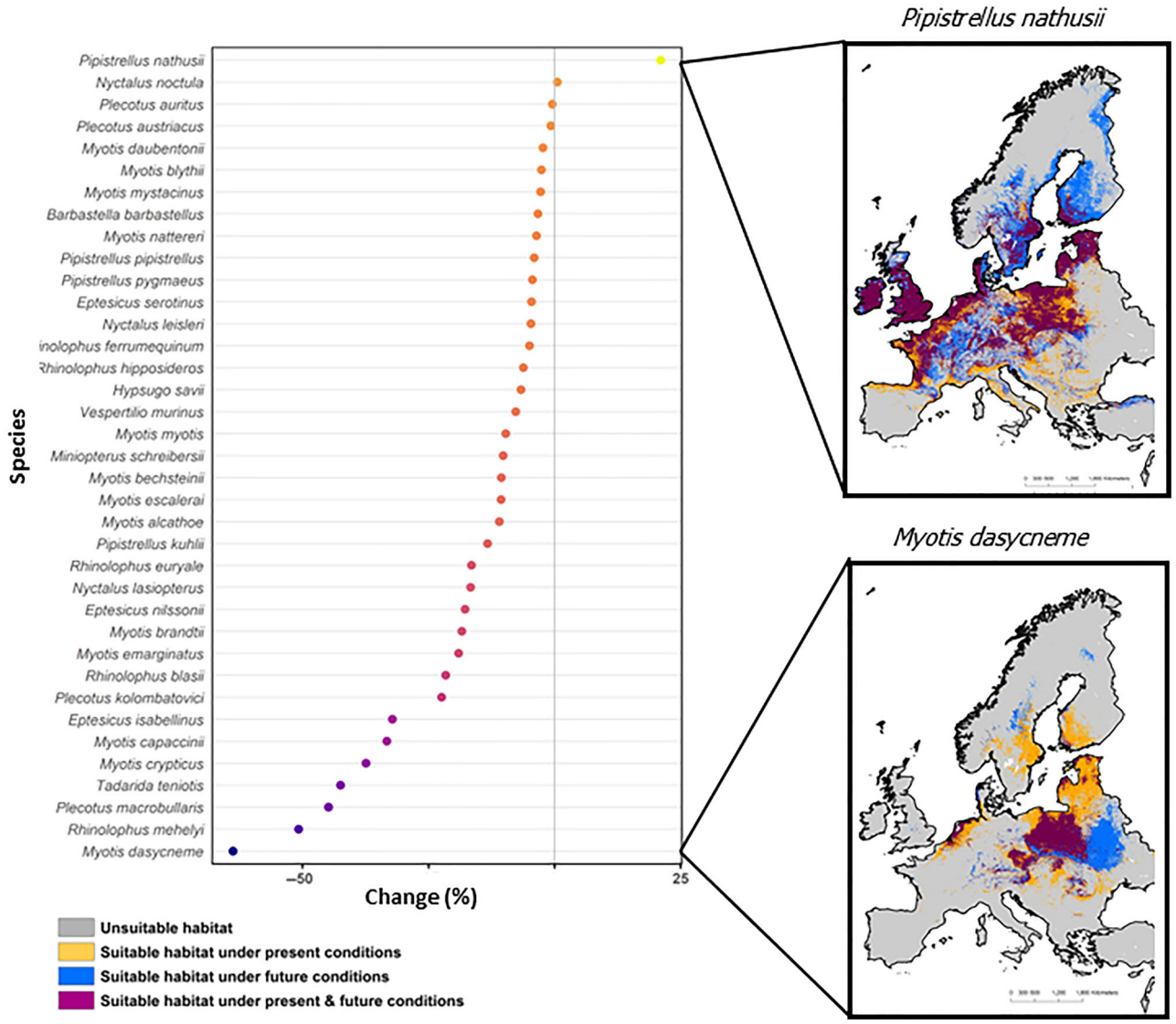

FIGURE 1 (a) Percent range change of each European bat species in the future under RCP (representative concentration pathway) 8.5 scenario for 2050 (0%, stable distribution; <0%, contracted distribution) and binary overlap map between current and future (2050) model predictions for (b) *Pipistrellus nathusii* (predicted to experience range gains) and (c) *Myotis dasycneme* (predicted to experience the greatest range losses).

traits. In contrast, in Spain and Italy, the thermal index trait appeared to be associated with the observed decrease in FD. However, in Finland, the decline in FD was closely associated with a reduction in species associated with boreal forests. Finally, in Eastern Europe, the predicted decrease in FD was predominantly linked to aspect ratio and body mass traits (Figure 5).

DISCUSSION

We assessed the potential impacts of climate change on the distribution, composition, and FD of bats at a continental scale. Our results predicted substantial shifts in range and FD across Europe, with notable range contractions for most bat species. Range contractions were predicted to occur in southern Europe, as European bats experience an overall shift in climatic suitability toward higher latitudes. These changes align with broader biodiversity trends and climate change predictions (Bilgin et al., 2012; Maclean & Wilson, 2011; Maiorano et al., 2011; Parmesan & Yohe, 2003; Rebelo et al., 2010). However, ours is the first study to relate such shifts to changes in composition and FD.

Predicted changes in species' range

Climate change is predicted to lead to the extinction of up to 10% of all European nonvolant mammals within the next century, with as many as 25% predicted to become critically endangered (Levinsky et al., 2007). A similar fate could affect bats in Europe because two thirds of the species we analyzed are

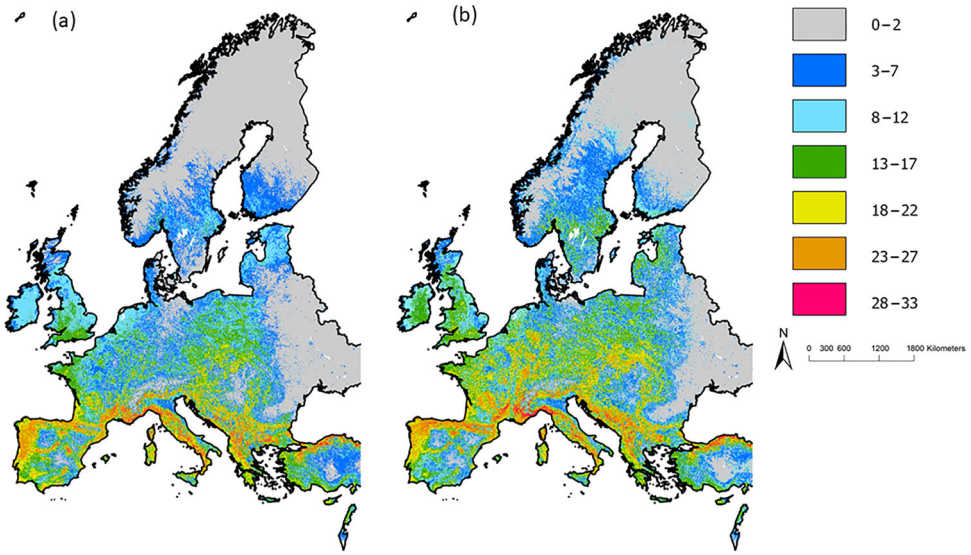

FIGURE 2 Modeled patterns of species richness of 37 European bats under (a) current and (b) future (RCP [representative concentration pathway] 8.5 scenario for 2050) climactic conditions.

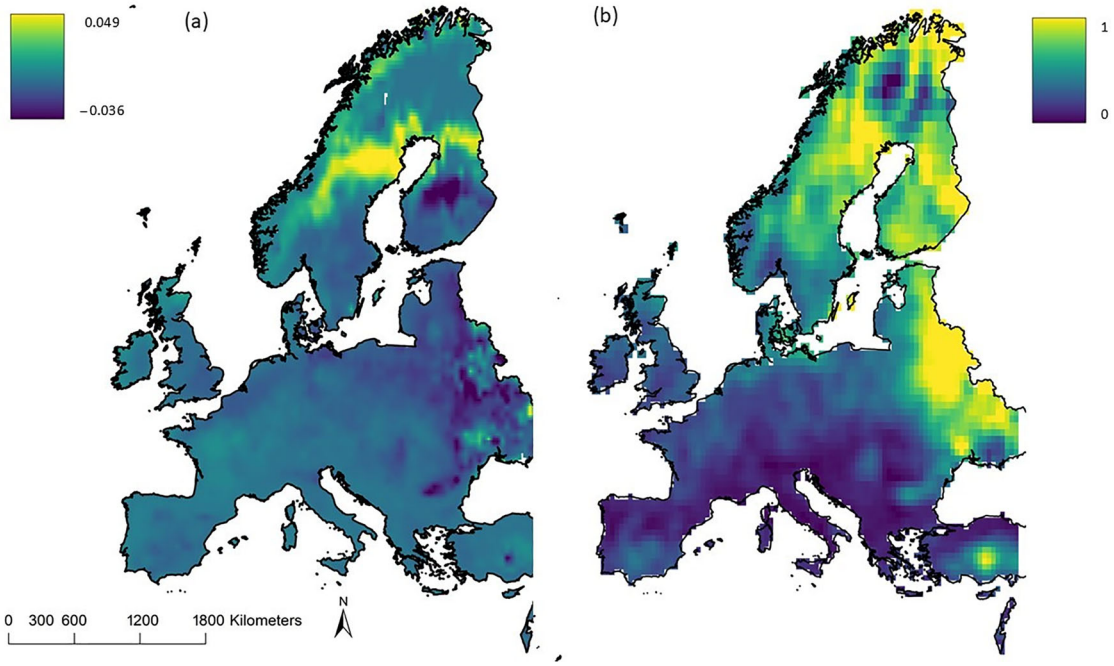

FIGURE 3 Predicted functional diversity (FD) and community turnover of 37 bat species across Europe currently and in 2050 under RCP (representative concentration pathway) 8.5 emissions scenario: (a) changes in functional diversity (Fdis) across 10 traits (values, absolute values; negative values, decrease in Fdis; positive values, increase in Fdis) and (b) community turnover (dark blue, no observed change in assemblage composition; yellow, change in assemblage composition).

already classified as endangered, vulnerable, or near threatened (IUCN, 2022). In our study, the predicted range losses for 33 out of 37 bat species by 2050 could cause population declines, increasing their vulnerability to loss of genetic diversity and evolutionary potential (Willi et al., 2006). Our predictions may be optimistic, given that bats may not be able to track their climatic niche at the pace of ongoing climate change due to their slow population growth rates, high philopatry, and long lifespans (Devictor et al., 2008). Even minor losses of habitat can lead to the extinction of local populations (McCarty, 2001), particularly when the species' ability to colonize and establish in new suitable areas is limited by dispersal barriers (García-Mudarra et al., 2009; Razgour, 2015), competition between species (Hall et al., 2016; Razgour et al., 2018; Salinas-Ramos et al., 2020,

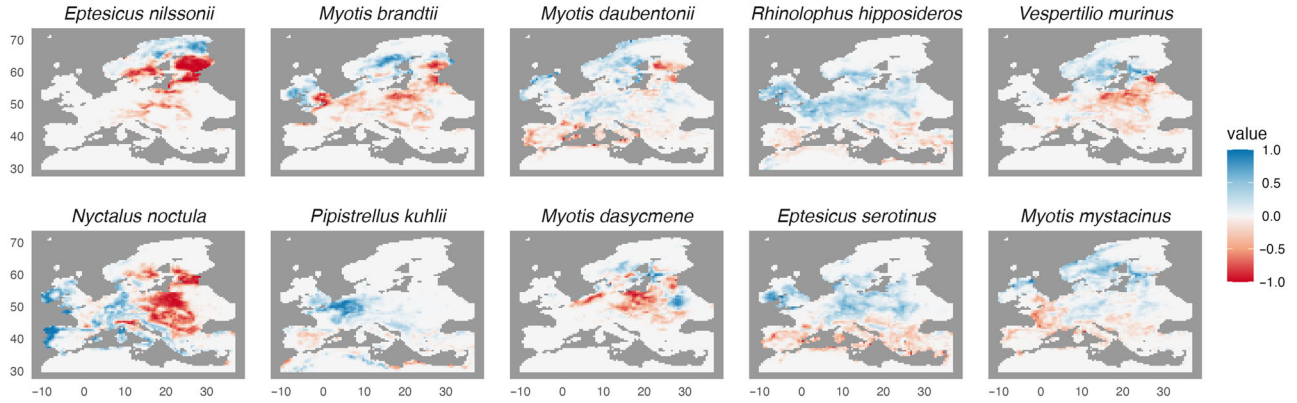

FIGURE 4 Predicted change in the distribution of the 10 species that contribute most to change in functional dispersion in order of their contribution (−1, 100% loss in 50 × 50-km cells; +1, 100% gain in 50 × 50-km cells).

2021; Smeraldo et al., 2021), food availability (Krauel et al., 2015), roost requirements (Loeb & Winters, 2013), or habitat fragmentation (Frey-Ehrenbold et al., 2013).

We found that most Mediterranean bat species were predicted to experience extensive range reductions. This is consistent with the findings of Rebelo et al. (2010) but contrasts with evidence of range expansion of some Mediterranean heat-tolerant species, such as *P. kuhlii*, over the last 2 decades (Ancillotto et al., 2016). However, despite the overall predicted ∼10% reduction in *P. kuhlii*'s range, range losses were predicted in southern Europe (especially Iberian and Italian Peninsulas) and parts of North Africa, whereas range was predicted to increase in more northern latitudes. This is in line with the trend observed over the past few decades, whereby *P. kuhlii* has been expanding its range into central and Eastern Europe (Sachanowicz et al., 2006). In contrast, range losses in southern Europe have not been recorded yet, possibly because they are more challenging to confirm than range expansions. Predicted range losses in southern Europe are of particular concern because the Iberian, Italian, and Balkan Peninsulas have supported bat populations over thousands of years, while more northern parts of Europe were covered by ice sheets and arctic tundra during Pleistocene glaciation events (e.g., *B. barbastellus* [Rebelo et al., 2012] and the *Myotis nattereri* species complex [Salicini et al., 2013]). As a result, bat populations in southern Europe tend to have higher levels of genetic diversity (e.g., Razgour et al., 2013) and, in turn, greater evolutionary potential and ability to adapt and respond to environmental change and diseases (Hoban et al., 2022). Mediterranean species, such as *R. mehelyi*, *T. teniotis*, *M. capaccinii*, and *E. isabellinus*, were predicted to experience the largest range contractions, 25–50%. This contraction poses a severe threat to their ability to respond to global change and consequently to their survival. Considering that *R. mehelyi* is already listed as endangered on the International Union for Conservation of Nature Red List (Russo & Cistrone, 2023a), climate change poses additional stress to this species, increasing the likelihood of extirpation and extinction. This is a concern also for other Mediterranean species classified as vulnerable, *M. capaccinii* (Russo & Cistrone, 2023b) and *Rhinolophus blasii* (Russo & Cistrone, 2023c).

The predicted impact of climate change extended beyond Mediterranean species, significantly affecting those in northern latitudes as well (Jetz et al., 2007; Kerr & Packer, 1998; Sala et al., 2000; Virkkala et al., 2008). Temperature increases are expected to be more pronounced in high latitudes (Meehl et al., 2007), potentially leading to the loss of suitable climatic conditions. This is evident in our projections of ∼70% (range across models: 57–70%) range reduction, the highest projected in our study, for *M. dasycneme*, a species found in northern and central Europe that is classified as vulnerable (Russo & Cistrone, 2023). A similar trend is predicted for *E. nilssonii* (18% range loss; range across models 13–21%). In contrast, *M. brandtii* and *M. mystacinus* were predicted to expand their ranges to northern latitudes despite a decrease in their overall ranges.

The predicted northward range expansion of some bat species may be limited by short summer nights, although we did not model this. In Fennoscandia, photoperiods change dramatically throughout the summer and extend to continuous daylight or brief periods of white nights that are still very bright (Speakman et al., 2000). *Myotis mystacinus* and *M. brandtii* are highly sensitive to light, emerging later than other bat species and avoiding flying in open spaces (Jones & Rydell, 1994; Spoelstra et al., 2017; Suominen et al., 2023). Adverse weather conditions at northern latitudes and short summer nights can cause a mismatch between energy expenditure and foraging opportunities, which can constraint the northern range expansion of many bat species (Fjelldal et al., 2023).

Not all European bat species were predicted to experience range losses under climate change. Some species were predicted to either maintain their current ranges or experience range expansions. The diverse responses of bat species to climate change can be attributed to a variety of factors, including ecological flexibility and differences in diet, roosting requirements, and physiological and reproductive strategies, which are likely to influence their resilience to changing climatic conditions (Loeb & Winters, 2013; Sherwin et al., 2013). The only species predicted to experience a substantial range increase was *P. nathusii*, a highly adaptive species (Lundy et al., 2010). This species has moved into novel habitats as a result of increasing temperatures, shifting its range in response to recent climate change at a Euro-

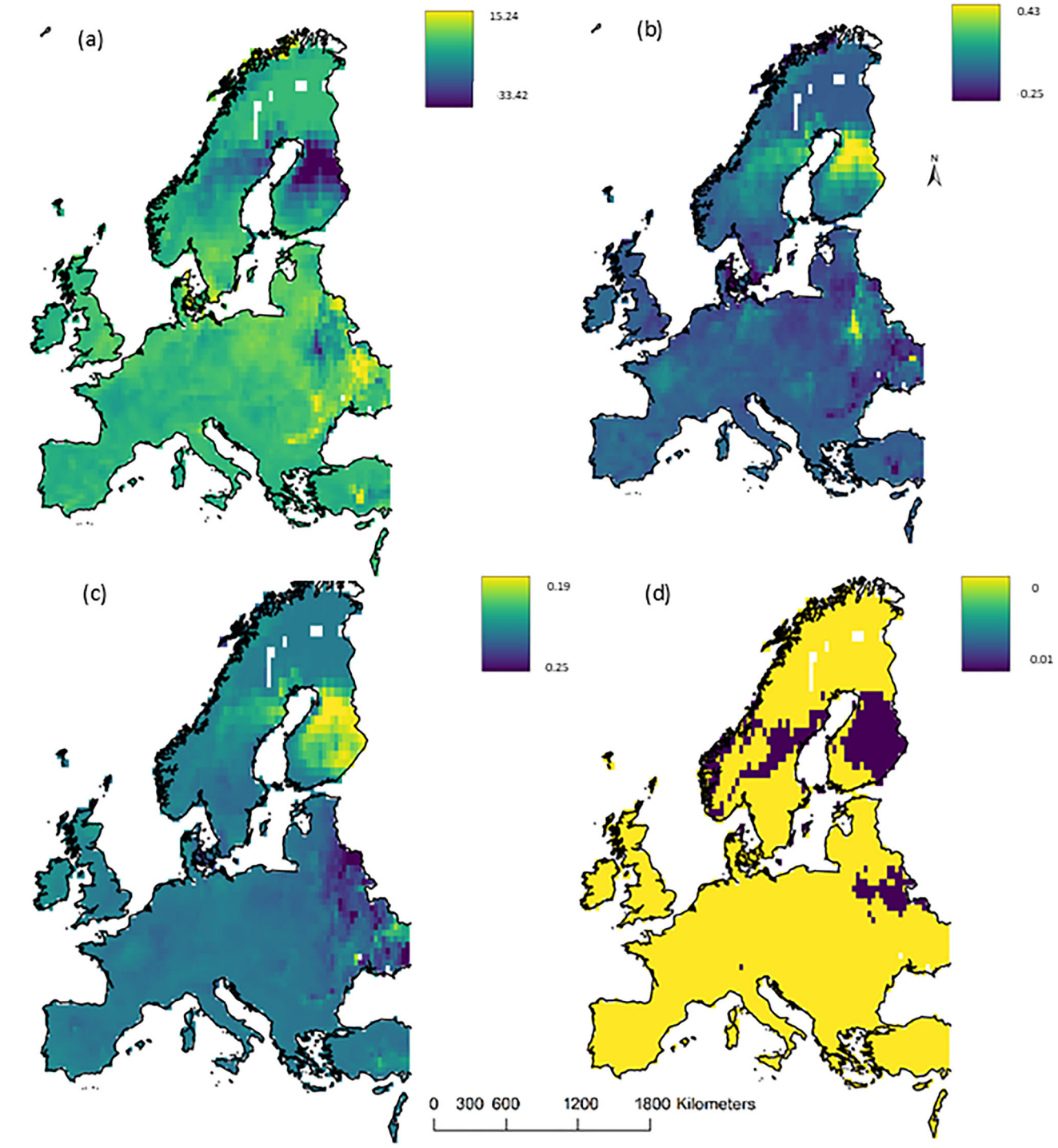

FIGURE 5 Predicted changes in modeled European bat species: (a) dietary specialization (dark blue, generalist species; yellow, specialist species), (b) diet diversity, (c) body mass, and (d) boreal forest foraging habitat (yellow, no association with boreal forest; dark blue, association with boreal forest; values in legends, absolute values for each range).

pean scale (Blomberg, Vasko, Salonen, et al., 2021; Lundy et al., 2010). Because *P. nathusii* is a long-distance migrant (Fleming et al., 2003), it can more easily reach new climatically suitable areas across Europe. Our results highlight the importance of considering species' ecological and physiological traits to better understand the variability in their sensitivity to climate change.

Changes in patterns of species richness

Our models predicted noticeable changes in patterns of bat species richness across Europe under climate change. Currently, areas with high bat species richness are predominantly found in southern Europe, particularly around the Mediterranean basin.

Our models predicted a decrease in species richness in these areas by 2050 and a corresponding increase in more northern latitudes. Similar trends were projected in previous modeling studies for other European mammals (Levinsky et al., 2007) and birds (Austin & Rehfisch, 2005; Huntley et al., 2008). We modeled only species that currently occur in Europe, so species losses in southern Europe could be compensated for by species expanding their ranges from North Africa and the Middle East. The future range contractions and expansions predicted here and the possible arrival of new species not currently occurring in Europe will create novel species assemblages, which could contribute to high spatiotemporal species turnover in future communities, resulting in new biotic interactions, such as competition (Blois et al., 2013) or host–parasite/host–pathogen interactions (Carlson et al., 2022).

The observed northward shifts in European Odonata and Lepidoptera due to warming (Hickling et al., 2005; Parmesan et al., 1999) suggest a potential increase in invertebrate diversity, which can support the predicted increased diversity and northward range shifts of insectivorous bats. This parallel trend underscores the interconnectedness of species range shifts in response to climate change. Nevertheless, the global decline in insect abundance and diversity (Forister et al., 2019) represents a significant ecological challenge for bat species, one that affects their primary food resources irrespective of their geographic distribution.

Changes in FD

The impact of climate change on patterns of FD has been understudied, especially in mammals (Thuiller et al., 2004). The predicted shifts in the distribution of suitable conditions for species under climate change are likely to drive changes in community structure and functional dynamics of bat populations across Europe, leading to functional changes (Salinas-Ramos et al., 2020). We predicted an increased functional dispersion in Northern Europe, apart from southern Finland, and decreases in Eastern Europe and parts of southern Spain. In line with our predictions, these trends were predominantly driven by a noticeable community turnover in northern and eastern parts of Europe, an increase in species richness in northern latitudes, and a decrease in southern Europe.

Predicted changes in range were responsible for functional dispersion change in *E. nilssonii*, *M. brandtii*, and *N. noctula* in Scandinavia; in *M. brandtii*, *V. murinus*, *N. noctula*, and *M. dasycneme* in Eastern Europe; and in *P. kuhlii*, *M. brandtii*, and *R. hipposideros* in northern Central Europe and the United Kingdom. Biodiversity is often linked to enhanced ecosystem functioning due to its presumed positive relationship with FD (Hooper et al., 2005). However, the relationship between species and FD can vary among ecosystems and functions different species perform (Cadotte et al., 2011; Liira & Jürjendal, 2023). As such, an increase in species diversity does not necessarily lead to improved ecosystem services and functioning. The trend of increasing species richness alongside a decrease in functional dispersion that we found in southern Finland and the eastern part of Europe suggests that although new functional types may be moving northward, the bulk of species arriving in those areas may be functionally similar or redundant. In contrast, species lost from these areas, such as *E. nilssonii*, *M. brandtii*, and *N. noctula*, represent the loss of unique traits, including larger body size and association with boreal forests. This implies that the functional advantages of increased biodiversity from expanding bat species in Europe may be limited, as has been seen in fish and bird communities (Barbet-Massin & Jetz, 2015; Pawluk et al., 2022). Functional redundancy (i.e., the similarity in functional traits among species [Walker, 1992]) is vital for ecosystem stability and resilience (Biggs et al., 2020). Acting as a buffer against the loss of species diversity, it helps maintain FD and is akin to an insurance policy for ecosystems (Gallagher et al., 2013; Gladstone-Gallagher et al., 2019). This redundancy supports ecosystem resilience under changing climates (Kahmen et al., 2005) and suggests that an increase in species diversity, coupled with stable or reduced functional dispersion, can lead to robust and resilient ecosystem services.

Of the functional traits we included in our analyses, our models predicted changes in the dietary traits of European bat species, which has implications for their ecological roles. In Fennoscandia, we predicted an increase in dietary diversity and niche breadth, coupled with a reduction in diet specialization. Contrasting trends were predicted for Eastern Europe, the eastern United Kingdom, Italy, and southern Spain. These changes in dietary traits and trait structures, driven by climate change, not only signify ecological shifts but also reflect potential impacts on ecosystem functioning (Schneider et al., 2016) and eventual predator–prey mismatch that could affect species survival (Thackeray et al., 2016).

The decline in bat FD in southern Finland can be attributed to the decline in species associated with boreal forests and species with more specialist diets. Climate change will change the tree species composition in southern Finland. Broadleaved deciduous tree species will replace Norway spruce, which will change the properties of forest habitats (Kellomäki et al., 2005). This poses a direct threat to bat species that rely on these forests for roosting, foraging, and breeding and could lead to a decline in their populations in these regions. Our functional analysis predicted that this community will be replaced by a community of bats with traits that are better matched to the new forest environment.

In Fennoscandia, the observed increase in FD among bats is attributed to, for example, large body mass. Such traits are generally associated with enhanced adaptability to varying climatic conditions (Pacifici et al., 2017). In contrast, Eastern Europe was predicted to see an increase in bats with small body mass, suggesting a potential reduction in adaptability to climate change (Mundinger et al., 2021; Salinas-Ramos et al., 2021). However, this observation in Eastern Europe should be interpreted with caution due to the lower density of records in some countries in this region. Nonetheless, these contrasting trends tend to reflect how different regions may experience varied impacts of climate change on bat physiology and, consequently, their ecological roles.

The overall predicted decrease in FD among bats is likely to have far-reaching negative consequences for other species and their associated ecosystem services. This is a critical concern. Because bats play a pivotal role in maintaining ecological balance through their functions, such as pest control (Kunz et al., 2011), their decline could lead to cascading ecological effects (Frick et al., 2020; Schmitt et al., 2021). This could also affect agriculture productivity, influence forest ecosystem functioning, and further increase reliance on chemical pesticides that harm the environment and threaten human health (Frank, 2024; Rani et al., 2021). The predicted impacts of the loss or gain of morphologically distinct species, such as *E. nilssonii* and *R. mehelyi*, in southern Finland and southern Spain, respectively, illustrate the functional importance of these species in their ecosystems. The decrease in FD of the local bat community may result in decreased diversity of the impacts of bats on ecosystems, including reduced top-down effects on different insect taxa because of a less diverse diet, and more restricted influence of bats on fewer habitat types. Moreover, a lower FD could lead to lower resilience to environmental change (Elmqvist et al., 2003). Given these potential consequences, it is important to understand which functional traits make bats particularly sensitive to climate change and how bat communities can be managed to retain key functions.

Conservation implications

Our findings underscore the urgent need for proactive and adaptive conservation strategies and coordinated international monitoring efforts to track bat responses to climate change at the continental scale. The results are being used to inform the development of a continental-scale monitoring network to track bat responses to climate change. The predicted northward shift in suitable conditions, coupled with the risks faced by species in southern Europe, presents a complex challenge that requires a multifaceted approach to conservation. Conservation efforts should focus on protecting and enhancing habitats and roosts in newly suitable areas and current ranges. Artificial roost creation may be needed in new areas that are climatically suitable, such as Fennoscandia, where underground natural roosts are limited (Blomberg, Vasko, Meierhofer, et al., 2021). In addition, there is a need for landscape-scale management strategies to increase landscape connectivity to facilitate range shifts under climate change by providing green corridors and reducing barriers to movement. Management strategies should take into account the complex interplay of ecological, climatic, and geographic factors that affect each species. We demonstrate the need to consider FD in conservation by targeting species with key functional traits, such as large body size and high dietary diversity, which are predicted to be lost in areas with high predicted losses in FD under climate change, such as southern Spain and parts of eastern Europe. This holistic approach is key not only for preserving bat populations but also for maintaining the critical ecosystem services bats

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REFERENCES

Aiello-Lammens, M. E., Boria, R. A., Radosavljevic, A., Vilela, B., & Anderson, R. P. (2015). spThin: An R package for spatial thinning of species occurrence records for use in ecological niche models. *Ecography*, *38*(5), 541–545.

Ancillotto, L., Santini, L., Ranc, N., Maiorano, L., & Russo, D. (2016). Extraordinary range expansion in a common bat: The potential roles of climate change and urbanisation. *Science of Nature*, *103*(3-4), Article 15. https://doi.org/10.1007/s00114-016-1334-7

Araújo, M. B., Anderson, R. P., Márcia Barbosa, A., Beale, C. M., Dormann, C. F., Early, R., Garcia, R. A., Guisan, A., Maiorano, L., & Naimi, B. (2019). Standards for distribution models in biodiversity assessments. *Science Advances*, *5*(1), Article eaat4858.

Austin, G. E., & Rehfisch, M. M. (2005). Shifting nonbreeding distributions of migratory fauna in relation to climatic change. *Global Change Biology*, *11*(1), 31–38.

Barbet-Massin, M., & Jetz, W. (2015). The effect of range changes on the functional turnover, structure and diversity of bird assemblages under future climate scenarios. *Global Change Biology*, *21*(8), 2917–2928.

Baselga, A., & Orme, C. D. L. (2012). Betapart: An R package for the study of beta diversity. *Methods in Ecology and Evolution*, *3*(5), 808–812.

Beck, J., Böller, M., Erhardt, A., & Schwanghart, W. (2014). Spatial bias in the GBIF database and its effect on modeling species' geographic distributions. *Ecological Informatics*, *19*, 10–15.

Biggs, C. R., Yeager, L. A., Bolser, D. G., Bonsell, C., Dichiera, A. M., Hou, Z., Keyser, S. R., Khursigara, A. J., Lu, K., Muth, A. F., Negrete, B., & Erisman, B. E. (2020). Does functional redundancy affect ecological stability and resilience? A review and meta-analysis. *Ecosphere*, *11*(7), Article e03184. https://doi.org/10.1002/ecs2.3184

Bilgin, R., Keşişoğlu, A., & Rebelo, H. (2012). Distribution patterns of bats in the eastern mediterranean region through a climate change perspective. *Acta Chiropterologica*, *14*(2), 425–437.

Blois, J. L., Zarnetske, P. L., Fitzpatrick, M. C., & Finnegan, S. (2013). Climate change and the past, present, and future of biotic interactions. *Science*, *341*(6145), 499–504.

Blomberg, A. S., Vasko, V., Meierhofer, M. B., Johnson, J. S., Eeva, T., & Lilley, T. M. (2021). Winter activity of boreal bats. *Mammalian Biology*, *101*(5), 609–618.

Blomberg, A. S., Vasko, V., Salonen, S., Petersons, G., & Lilley, T. M. (2021). First record of a Nathusius' pipistrelle (*Pipistrellus nathusii*) overwintering at a latitude above 60°N. *Mammalia*, *85*(1), 74–78.

Brodie, J. F., Williams, S., & Garner, B. (2021). The decline of mammal functional and evolutionary diversity worldwide. *Proceedings of the National Academy of Sciences of the United States of America*, *118*(3), Article e1921849118. https://doi.org/10.1073/pnas.1921849118/

Cadotte, M. W., Carscadden, K., & Mirotchnick, N. (2011). Beyond species: Functional diversity and the maintenance of ecological processes and services. *Journal of Applied Ecology*, *48*, 1079–1087.

Carlson, C. J., Albery, G. F., Merow, C., Trisos, C. H., Zipfel, C. M., Eskew, E. A., Olival, K. J., Ross, N., & Bansal, S. (2022). Climate change increases cross-species viral transmission risk. *Nature*, *607*(7919), 555–562.

Chen, I. C., Hill, J. K., Ohlemüller, R., Roy, D. B., & Thomas, C. D. (2011). Rapid range shifts of species associated with high levels of climate warming. *Science*, *333*(6045), 1024–1026.

Clavel, J., Julliard, R., & Devictor, V. (2011). Worldwide decline of specialist species: Toward a global functional homogenization? *Frontiers in Ecology and the Environment*, *9*(4), 222–228.

Devictor, V., Julliard, R., Couvet, D., & Jiguet, F. (2008). Birds are tracking climate warming, but not fast enough. *Proceedings of the Royal Society B: Biological Sciences*, *275*(1652), 2743–2748.

Dullinger, S., Gattringer, A., Thuiller, W., Moser, D., Zimmermann, N. E., Guisan, A., Willner, W., Plutzar, C., Leitner, M., Mang, T., Caccianiga, M., Dirnböck, T., Ertl, S., Fischer, A., Lenoir, J., Svenning, J. C., Psomas, A., Schmatz, D. R., Silc, U., … Hülber, K. (2012). Extinction debt of high-mountain plants under twenty-first-century climate change. *Nature Climate Change*, *2*(8), 619–622.

Elith, J., Kearney, M., & Phillips, S. (2010). The art of modelling range-shifting species. *Methods in Ecology and Evolution*, *1*, 330–342.

Elith, J., Leathwick, J. R., & Hastie, T. (2008). A working guide to boosted regression trees. *Journal of Animal Ecology*, *77*(4), 802–813.

Elmqvist, T., Folke, C., Nyström, M., Peterson, G., Bengtsson, J., Walker, B., & Norberg, J. (2003). Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and the Environment*, *1*(9), 488–494.

Festa, F., Ancillotto, L., Santini, L., Pacifici, M., Rocha, R., Toshkova, N., Amorim, F., Benítez-López, A., Domer, A., Hamidović, D., Kramer-Schadt, S., Mathews, F., Radchuk, V., Rebelo, H., Ruczynski, I., Solem, E., Tsoar, A., Russo, D., & Razgour, O. (2022). Bat responses to climate change: A systematic review. *Biological Reviews*, *98*(1), 19–33. https://doi.org/10.1111/brv.12893

Fjelldal, M. A., Muller, A. S., Ratikainen, I. I., Stawski, C., & Wright, J. (2023). The small-bat-in-summer paradigm: Energetics and adaptive behavioural routines of bats investigated through a stochastic dynamic model. *Journal of Animal Ecology*, *92*(10), 2078–2093.

Fleming, T. H., Eby, P., Kunz, T. H., & Fenton, M. B. (2003). Ecology of bat migration. *Bat Ecology*, *156*, 164–165.

Forister, M. L., Pelton, E. M., & Black, S. H. (2019). Declines in insect abundance and diversity: We know enough to act now. *Conservation Science and Practice*, *1*(8), Article e80.

Frank, E. G. (2024). The economic impacts of ecosystem disruptions: Costs from substituting biological pest control. *Science*, *385*(6713), Article eadg0344.

Frey-Ehrenbold, A., Bontadina, F., Arlettaz, R., & Obrist, M. K. (2013). Landscape connectivity, habitat structure and activity of bat guilds in farmland-dominated matrices. *Journal of Applied Ecology*, *50*(1), 252–261.

Frick, W. F., Kingston, T., & Flanders, J. (2020). A review of the major threats and challenges to global bat conservation. *Annals of the New York Academy of Sciences*, *1469*(1), 5–25.

Froidevaux, J. S. P., Toshkova, N., Barbaro, L., Benítez-López, A., Kerbiriou, C., Le Viol, I., Pacifici, M., Santini, L., Stawski, C., Russo, D., Dekker, J., Alberdi, A., Amorim, F., Ancillotto, L., Barré, K., Bas, Y., Cantú-Salazar, L., Dechmann, D. K. N., Devaux, T., … Razgour, O. (2023). A species-level trait dataset of bats in Europe and beyond. *Scientific Data*, *10*, Article 253. https://doi.org/10.1038/s41597-023-02157-4

Gallagher, R. V., Hughes, L., & Leishman, M. R. (2013). Species loss and gain in communities under future climate change: Consequences for functional diversity. *Ecography*, *36*(5), 531–540.

García-Mudarra, J. L., Ibáñez, C., & Juste, J. (2009). The Straits of Gibraltar: Barrier or bridge to Ibero-Moroccan bat diversity? *Biological Journal of the Linnean Society*, *96*(2), 434–450.

Gladstone-Gallagher, R. V., Pilditch, C. A., Stephenson, F., & Thrush, S. F. (2019). Linking traits across ecological scales determines functional resilience. *Trends in Ecology and Evolution*, *34*(12), 1080–1091.

Hackländer, K., & Zachos, F. E. (2020). The new handbook of the mammals of Europe: Background and introduction. In K. Hackländer & F. E. Zachos (Eds.), *Mammals of Europe—Past, present, and future* (pp. 1–7). Springer.

Hall, L. K., Lambert, C. T., Larsen, R. T., Knight, R. N., & McMillan, B. R. (2016). Will climate change leave some desert bat species thirstier than others? *Biological Conservation*, *201*, 284–292.

Hickling, R., Roy, D. B., Hill, J. K., & Thomas, C. D. (2005). A northward shift of range margins in British Odonata. *Global Change Biology*, *11*(3), 502–506.

Hijmans, R. J., Phillips, S., Leathwick, J., Elith, J., & Hijmans, M. R. J. (2017). Package 'dismo'. *Circles*, *9*, 1–68.

Hijmans, R. J., Van Etten, J., Cheng, J., Mattiuzzi, M., Sumner, M., Greenberg, J. A., Lamigueiro, O. P., Bevan, A., Racine, E. B., & Shortridge, A. (2015). *Package 'raster'*. R package 734:473.

Hoban, S., Archer, F. I., Bertola, L. D., Bragg, J. G., Breed, M. F., Bruford, M. W., Coleman, M. A., Ekblom, R., Funk, W. C., Grueber, C. E., Hand, B. K., Jaffé, R., Jensen, E., Johnson, J. S., Kershaw, F., Liggins, L., MacDonald, A. J., Mergeay, J., Miller, J. M., … Hunter, M. E. (2022). Global genetic diversity status and trends: Towards a suite of Essential Biodiversity Variables (EBVs) for genetic composition. *Biological Reviews*, *97*(4), 1511–1538.

Hooper, D. U., Chapin, F. S., Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J. H., Lodge, D. M., Loreau, M., Naeem, S., Schmid, B., Setälä, H., Symstad, A. J., Vandermeer, J., & Wardle, D. A. (2005). Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecological Monographs*, *75*(1), 3–35.

Huntley, B., Collingham, Y. C., Willis, S. G., & Green, R. E. (2008). Potential impacts of climatic change on European breeding birds. *PLoS ONE*, *3*(1), Article e1439. https://doi.org/10.1371/journal.pone.0001439

Hutterer, R., Ivanova, T., Meyer-Cords, C., & Rodrigues, L. (2005). *Bat migrations in Europe: A review of banding data and literature*. BfN-Schriftenvertrieb im Landwirtschaftsverlag.

IPCC. (2013). Climate Change 2013: The Physical Science Basis. *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, et al., Eds.). Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/

IPCC. (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, et al., Eds.). Cambridge University Press. https://doi.org/10.1017/9781009325844

IUCN. (2022). The IUCN Red List of Threatened Species. Version 2022-2. https://www.iucnredlist.org

Jetz, W., Wilcove, D. S., & Dobson, A. P. (2007). Projected impacts of climate and land-use change on the global diversity of birds. *PLoS Biology*, *5*(6), Article e157.

Jones, G., Jacobs, D. S., Kunz, T. H., Wilig, M. R., & Racey, P. A. (2009). Carpe noctem: The importance of bats as bioindicators. *Endangered Species Research*, *8*(1–2), 93–115.

Jones, G., & Rydell, J. (1994). Foraging strategy and predation risk as factors influencing emergence time in echolocating bats. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *346*, 445–455.

Kahmen, A., Perner, J., & Buchmann, N. (2005). Diversity-dependent productivity in semi-natural grasslands following climate perturbations. *Functional Ecology*, *19*(4), 594–601.

Karger, D. N., Conrad, O., Böhner, J., Kawohl, T., Kreft, H., Soria-Auza, R. W., Zimmermann, N. E., Linder, H. P., & Kessler, M. (2017). Climatologies at high resolution for the earth's land surface areas. *Scientific Data*, *4*, Article 170122. https://doi.org/10.1038/sdata.2017.122

Kellomäki, S., Strandman, H., Nuutinen, T., Peltola, H., Korhonen, K. T., & Väisänen, H. (2005). *Adaptation of forest ecosystems, forests and forestry to climate change* (FINADAPT Working Paper 4; Mimeographs 334). Finnish Environment Institute.

Kerr, J., & Packer, L. (1998). The impact of climate change on mammal diversity in Canada. *Environmental Monitoring and Assessment*, *49*, 263–270.

Korine, C., Adams, R., Russo, D., Fisher-Phelps, M., & Jacobs, D. (2016). Bats and water: Anthropogenic alterations threaten global bat populations. In C. Voigt & T. Kingston (Eds.), *Bats in the Anthropocene: Conservation of bats in a changing world* (pp. 215–241). Springer.

Krauel, J. J., Westbrook, J. K., & Mccracken, G. F. (2015). Weather-driven dynamics in a dual-migrant system: Moths and bats. *Journal of Animal Ecology*, *84*(3), 604–614.

Kunz, T. H., de Torrez, E. B., Bauer, D., Lobova, T., & Fleming, T. H. (2011). Ecosystem services provided by bats. *Annals of the New York Academy of Sciences*, *1223*(1), 1–38.

Laliberté, E., & Legendre, P. (2010). A distance-based framework for measuring functional diversity from multiple traits. *Ecology*, *91*(1), 299–305.

Laliberté, E., Legendre, P., Shipley, B., & Laliberté, M. E. (2014). *Package 'fd': Measuring functional diversity from multiple traits, and other tools for functional ecology*. R package version 1.0-12.

Lek, S., & Guégan, J.-F. (1999). Artificial neural networks as a tool in ecological modelling, an introduction. *Ecological Modelling*, *120*(2–3), 65–73.

Levinsky, I., Skov, F., Svenning, J. C., & Rahbek, C. (2007). Potential impacts of climate change on the distributions and diversity patterns of European mammals. *Biodiversity and Conservation*, *16*(13), 3803–3816. https://doi.org/10.1007/s10531-007-9181-7

Liira, J., & Jürjendal, I. (2023). Are bees attracted by flower richness? Implications for ecosystem service-based policy. *Ecological Indicators*, *154*, Article 110927.

Liu, C., White, M., Newell, G., & Griffioen, P. (2013). Species distribution modelling for conservation planning in Victoria, Australia. *Ecological Modelling*, *249*, 68–74.

Loeb, S. C., & Winters, E. A. (2013). Indiana bat summer maternity distribution: Effects of current and future climates. *Ecology and Evolution*, *3*(1), 103–114. https://doi.org/10.1002/ece3.440

Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J. P., Hector, A., Hooper, D. U., Huston, M. A., Raffaelli, D., & Schmid, B. (2001). Biodiversity and ecosystem functioning: Current knowledge and future challenges. *Science*, *294*(5543), 804–808.

Lundy, M., Montgomery, I., & Russ, J. (2010). Climate change-linked range expansion of Nathusius' pipistrelle bat, *Pipistrellus nathusii* (Keyserling & Blasius, 1839). *Journal of Biogeography*, *37*(12), 2232–2242.

Maclean, I. M. D., & Wilson, R. J. (2011). Recent ecological responses to climate change support predictions of high extinction risk. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(30), 12337–12342.

Maiorano, L., Falcucci, A., Zimmermann, N. E., Psomas, A., Pottier, J., Baisero, D., Rondinini, C., Guisan, A., & Boitani, L. (2011). The future of terrestrial mammals in the Mediterranean basin under climate change. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*(1578), 2681–2692.

Mäntylä, E., Klemola, T., & Laaksonen, T. (2011). Birds help plants: A meta-analysis of top-down trophic cascades caused by avian predators. *Oecologia*, *165*(1), 143–151.

Maxwell, S. L., Fuller, R. A., Brooks, T. M., & Watson, J. E. M. (2016). Biodiversity: The ravages of guns, nets and bulldozers. *Nature*, *536*(7615), 143–145.

McCarthy, N., Lipper, L., & Branca, G. (2011). *Climate smart agriculture: Smallholder adoption and implications for climate change adaptation and mitigation*. FAO Mitigation of Climate Change in Agriculture Working Paper.

McCarty, J. P. (2001). Consecuencias Biológicas de Cambios Climáticos Recientes [Ecological consequences of recent climate change]. *Conservation Biology*, *15*(2), 320–331.

McCullagh, P., & Nelder, J. A. (1989). *Generalized Linear Models*. 2nd Edition, Chapman and Hall, London. http://dx.doi.org/10.1007/978-1-4899-3242-6

McKinney, M. L., & Lockwood, J. L. (1999). Biotic homogenization: A few winners replacing many losers in the next mass extinction. *Trends in Ecology & Evolution*, *14*(11), 450–453.

Meehl, G. A., Covey, C., Delworth, T., Latif, M., McAvaney, B., Mitchell, J. F. B., Stouffer, R. J., & Taylor, K. E. (2007). The WCRP CMIP3 multimodel dataset: A new era in climate change research. *Bulletin of the American Meteorological Society*, *88*(9), 1383–1394.

Merow, C., Smith, M. J., & Silander, J. A. (2013). A practical guide to MaxEnt for modeling species' distributions: What it does, and why inputs and settings matter. *Ecography*, *36*(10), 1058–1069.

Mundinger, C., Scheuerlein, A., & Kerth, G. (2021). Long-term study shows that increasing body size in response to warmer summers is associated with a higher mortality risk in a long-lived bat species. *Proceedings of the Royal Society B: Biological Sciences*, *288*(1952), Article 20210508.

Pacifici, M., Visconti, P., Butchart, S. H. M., Watson, J. E. M., Cassola, F. M., & Rondinini, C. (2017). Species' traits influenced their response to recent climate change. *Nature Climate Change*, *7*(3), 205–208.

Parmesan, C., Ryrholm, N., Stefanescu, C., Hill, J. K., Thomas, C. D., Descimon, H., Huntley, B., Kaila, L., Kullberg, J., & Tammaru, T. (1999). Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature*, *399*(6736), 579–583.

Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change. *Nature*, *421*, 37–42.

Pawluk, M., Fujiwara, M., & Martinez-Andrade, F. (2022). Climate change linked to functional homogenization of a subtropical estuarine system. *Ecology and Evolution*, *12*(4), Article e8783. https://doi.org/10.1002/ece3.8783

Penone, C., Davidson, A. D., Shoemaker, K. T., Di Marco, M., Rondinini, C., Brooks, T. M., Young, B. E., Graham, C. H., & Costa, G. C. (2014). Imputation of missing data in life-history trait datasets: Which approach performs the best? *Methods in Ecology and Evolution*, *5*(9), 961–970.

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, *190*(3–4), 231–259.

Rani, L., Thapa, K., Kanojia, N., Sharma, N., Singh, S., Grewal, A. S., Srivastav, A. L., & Kaushal, J. (2021). An extensive review on the consequences of chemical pesticides on human health and environment. *Journal of Cleaner Production*, *283*, Article 124657.

Razgour, O., Juste, J., Ibáñez, C., Kiefer, A., Rebelo, H., Puechmaille, S. J., Arlettaz, R., Burke, T., Dawson, D. A., Beaumont, M., & Jones, G. (2013). The shaping of genetic variation in edge-of-range populations under past and future climate change. *Ecology Letters*, *16*(10), pp.1258–1266.

Razgour, O. (2015). Beyond species distribution modeling: A landscape genetics approach to investigating range shifts under future climate change. *Ecological Informatics*, *30*, 250–256.

Razgour, O., Persey, M., Shamir, U., & Korine, C. (2018). The role of climate, water and biotic interactions in shaping biodiversity patterns in arid environments across spatial scales. *Diversity and Distributions*, *24*(10), 1440–1452.

Rebelo, H., Tarroso, P., & Jones, G. (2010). Predicted impact of climate change on European bats in relation to their biogeographic patterns. *Global Change Biology*, *16*(2), 561–576.

Rebelo, H., Froufe, E., Ferrand, N., & Jones, G. (2012). Integrating molecular ecology and predictive modelling: implications for the conservation of the barbastelle bat (Barbastella barbastellus) in Portugal. *European Journal of Wildlife Research*, *58*, pp. 721–732.

Robillard, C. M., Coristine, L. E., Soares, R. N., & Kerr, J. T. (2015). Facilitating climate-change-induced range shifts across continental land-use barriers. *Conservation Biology*, *29*(6), 1586–1595.

Rosenfeld, J. S. (2002). Functional redundancy in ecology and conservation. *Oikos*, *98*(1), 156–162.

Rowe, R. J., Finarelli, J. A., & Rickart, E. A. (2010). Range dynamics of small mammals along an elevational gradient over an 80-year interval. *Global Change Biology*, *16*(11), 2930–2943.

Roy, D. B., Oliver, T. H., Botham, M. S., Beckmann, B., Brereton, T., Dennis, R. L. H., Harrower, C., Phillimore, A. B., & Thomas, J. A. (2015). Similarities in butterfly emergence dates among populations suggest local adaptation to climate. *Global Change Biology*, *21*(9), 3313–3322.

Russo, D., & Cistrone, L. (2023a). *Rhinolophus mehelyi (Europe assessment)*. The IUCN Red List of Threatened Species 2023: e.T19515A216726767. International Union for Conservation of Nature.

Russo, D., & Cistrone, L. (2023b). *Myotis capaccinii (Europe assessment)*. The IUCN Red List of Threatened Species 2023: e.T14126A216724016. International Union for Conservation of Nature.

Russo, D., & Cistrone, L. (2023c). *Rhinolophus blasii (Europe assessment)*. The IUCN Red List of Threatened Species 2023: e.T19515A216726767. International Union for Conservation of Nature.

Russo, D., & Cistrone, L. (2023). Myotis dasycneme (Europe assessment) (errata version published in 2024). *The IUCN Red List of Threatened Species 2023: e.T14127A254043181*. International Union for Conservation of Nature.

Sachanowicz, K., Wower, A., & Bashta, A. T. (2006). Further range extension of *Pipistrellus kuhlii* (Kuhl, 1817) in central and eastern Europe. *Acta Chiropterologica*, *8*, 543–548.

Sala, O. E., Stuart Chapin, F., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L. F., Jackson, R. B., & Kinzig, A. (2000). Global biodiversity scenarios for the year 2100. *Science*, *287*(5459), 1770–1774.

Salicini, I., Ibáñez, C., & Juste, J. (2013). Deep differentiation between and within Mediterranean glacial refugia in a flying mammal, the Myotis nattereri bat complex. *Journal of Biogeography*, *40*(6), pp.1182–1193.

Salinas-Ramos, V. B., Agnelli, P., Bosso, L., Ancillotto, L., & Russo, D. (2021). Body size of Italian greater horseshoe bats (*Rhinolophus ferrumequinum*) increased over one century and a half: A response to climate change? *Mammalian Biology*, *101*(6), 1127–1131.

Salinas-Ramos, V. B., Ancillotto, L., Bosso, L., Sánchez-Cordero, V., & Russo, D. (2020). Interspecific competition in bats: State of knowledge and research challenges. *Mammal Review*, *50*(1), 68–81.

Schipper, A. M., Hilbers, J. P., Meijer, J. R., Antão, L. H., Benítez-López, A., de Jonge, M. M. J., Leemans, L. H., Scheper, E., Alkemade, R., Doelman, J. C., Mylius, S., Stehfest, E., van Vuuren, D. P., van Zeist, W. J., & Huijbregts, M. A. J. (2020). Projecting terrestrial biodiversity intactness with GLOBIO 4. *Global Change Biology*, *26*(2), 760–771.

Schmitt, L., Greenberg, R., Ibarra-Núñez, G., Bichier, P., Gordon, C. E., & Perfecto, I. (2021). Cascading effects of birds and bats in a shaded coffee agroforestry system. *Frontiers in Sustainable Food Systems*, *5*, Article 512998. https://doi.org/10.3389/fsufs.2021.512998

Schneider, F. D., Brose, U., Rall, B. C., & Guill, C. (2016). Animal diversity and ecosystem functioning in dynamic food webs. *Nature Communications*, *7*, Article 12718. https://doi.org/10.1038/ncomms12718

Sherwin, H. A., Montgomery, W. I., & Lundy, M. G. (2013). The impact and implications of climate change for bats. *Mammal Review*, *43*(3), 171–182.

Smeraldo, S., Bosso, L., Salinas-Ramos, V. B., Ancillotto, L., Sánchez-Cordero, V., Gazaryan, S., & Russo, D. (2021). Generalists yet different: Distributional responses to climate change may vary in opportunistic bat species sharing similar ecological traits. *Mammal Review*, *51*(4), 571–584.

Speakman, J. R., Rydell, J., Webb, P. I., Hayes, J. P., Hays, G. C., Hulbert, I. A. R., & Mcdevitt, R. M. (2000). Activity patterns of insectivorous bats and birds in Northern Scandinavia (69° N), during continuous midsummer daylight. *Oikos*, *88*(1), 75–86.

Spoelstra, K., van Grunsven, R. H. A., Ramakers, J. J. C., Ferguson, K. B., Raap, T., Donners, M., Veenendaal, E. M., & Visser, M. E. (2017). Response of bats to light with different spectra: Light-shy and agile bat presence is affected by white and green, but not red light. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1855), Article 20170075. https://doi.org/10.1098/rspb.2017.0075

Stebbings, R. E., & Griffith, F. (1986). *Distribution and status of bats in Europe*. Institute of Terrestrial Ecology.

Stekhoven, D. J., & Bühlmann, P. (2012). MissForest—Non-parametric missing value imputation for mixed-type data. *Bioinformatics*, *28*(1), 112–118.

Stewart, K., Carmona, C. P., Clements, C., Venditti, C., Tobias, J. A., & González-Suárez, M. (2023). Functional diversity metrics can perform well with highly incomplete data sets. *Methods in Ecology and Evolution*, *14*(11), 2856–2872.

Suominen, K. M., Vesterinen, E. J., Kivistö, I., Reiman, M., Virtanen, T., Meierhofer, M. B., Vasko, V., Sironen, T., & Lilley, T. M. (2023). Environmental features around roost sites drive species-specific roost preferences for boreal bats. *Global Ecology and Conservation*, *46*, Article e02589. https://doi.org/10.1016/j.gecco.2023.e02589

Tannerfeldt, M., Elmhagen, B., & Angerbjörn, A. (2002). Exclusion by interference competition? The relationship between red and arctic foxes. *Oecologia*, *132*(2), 213–220.

Thackeray, S. J. (2016). Phenological sensitivity to climate across taxa and trophic levels. *Nature*, *535*(7611), 241–245. https://doi.org/10.1038/nature18608

Thévenin, C., Mouchet, M., Robert, A., Kerbiriou, C., & Sarrazin, F. (2022). Functional representativeness and distinctiveness of reintroduced birds and mammals in Europe. *Scientific Reports*, *12*(1), Article 4081. https://doi.org/10.1038/s41598-022-07991-x

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., Erasmus, B. F. N., De Siqueira, M. F., Grainger, A., & Hannah, L. (2004). Extinction risk from climate change. *Nature*, *427*(6970), 145–148.

Thuiller, W., Araújo, M. B., Pearson, R. G., Whittaker, R. J., Brotons, L., & Lavorel, S. (2004). Uncertainty in predictions of extinction risk. *Nature*, *430*(6995), 34–34.

Thuiller, W., Georges, D., Engler, R., Breiner, F., Georges, M. D., & Thuiller, C. W. (2016). *Package 'biomod2': Species distribution modeling within an ensemble forecasting framework*. R package.

Thuiller, W., Lavorel, S., Sykes, M. T., & Araújo, M. B. (2006). Using niche-based modelling to assess the impact of climate change on tree functional diversity in Europe. *Diversity and Distributions*, *12*(1), 49–60.

Valavi, R., Elith, J., Lahoz-Monfort, J. J., & Guillera-Arroita, G. (2019). blockCV: An R package for generating spatially or environmentally separated folds for k-fold cross-validation of species distribution models. *Methods in Ecology and Evolution*, *10*(2), 225–232.

Vignali, S., Barras, A. G., Arlettaz, R., & Braunisch, V. (2020). SDMtune: An R package to tune and evaluate species distribution models. *Ecology and Evolution*, *10*(20), 11488–11506.

Virkkala, R., Heikkinen, R. K., Leikola, N., & Luoto, M. (2008). Projected large-scale range reductions of northern-boreal land bird species due to climate change. *Biological Conservation*, *141*(5), 1343–1353.

Walker, B. H. (1992). Biodiversity and ecological redundancy. *Conservation Biology*, *6*(1), 18–23.

Walther, G.-R., Post, E., Convey, P., Menzel, A., Parmesank, C., Beebee, T. J. C., Fromentin, J.-M., Hoegh-Guldberg, O., & Bairlein, F. (2002). Ecological responses to recent climate change. *Nature*, *416*, 389–395.

Willi, Y., Van Buskirk, J., & Hoffmann, A. A. (2006). Limits to the adaptive potential of small populations. *Annual Review of Ecology, Evolution, and Systematics*, *37*, 433–458.

Williams, J. W., & Jackson, S. T. (2007). Novel climates, no-analog communities, and ecological surprises. *Frontiers in Ecology and the Environment*, *5*(9), 475–482.

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