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Risk assessment for Iberian birds under global change

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A B S T R A C T

Conservation priority areas and programs are often established without consideration of future changes in species distributions. However, global change is expected to threaten the persistence of several species while offering opportunities for range expansion to others. In this study, building on previous work, we develop and implement an approach to classify bird species according to their degree of exposure and vulnerability to future climate and land-use change, including climatically driven changes in vegetation. To examine species exposure to environmental changes, we first fitted environmental envelope models and projected then into the future under scenarios of climate, land use and vegetation change. Then, we estimated species vulnerability by taking into account traits that are expected to render species vulnerable to environmental change while considering, simultaneously, the current IUCN conservation status of species. Our results show that bird species highly (and negatively) exposed to future environmental changes are currently less threatened and possess characteristics that render them less susceptible to local extinction than species that are less exposed. Our results reinforce the need to complement studies of global change impacts on biodiversity, typically based on assessments of species exposure to changes, with additional information related to the ability of species to persist under such changes. Nevertheless, we stress that while combining different sources of information is important, it is the comparison of outcomes from these different sources of information that enables development of alternative management strategies. Depending on the source of risk (e.g., exposure to global change versus vulnerability traits to multiple stressors) alternative conservation actions might be required.

1. Introduction

There is growing evidence that global environmental changes are already affecting biodiversity and their effects are expected to become greater during the 21st century (e.g., Chen et al., 2011; Parmesan, 2006). An increasing number of studies have used environmental envelope models to explore the impacts of global change on biodiversity (e.g., Garcia et al., 2011; Thuiller et al., 2005b). These models relate known species distributions to environmental variables to characterize current potential distributions and project future potential distributions under global change. Environmental envelope models provide an estimate of the level of exposure of species to global change, but they do not characterize species vulnerability to these changes (Araújo and Peterson, 2012). Therefore, for a given level of exposure, species will have varying abilities to respond to it. In order to carry out species risk assessments in the context of global change, it would be desirable, whenever possible, to combine measurements of exposure to threats with measurements of species vulnerability to them (e.g., Arribas et al., 2012; Dawson et al., 2011; Foden et al., 2008, 2013; Williams et al., 2008). In this study, species vulnerability is defined as the species inherent capacity to cope with environmental changes independently of the level of exposure to them (Araújo and Williams, 2000).

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A species capacity to persist under global change conditions depends on a variety of biological characteristics including intrinsic species characteristics, such as fecundity rate, and other non-organismal characteristics such as range size. For the sake of simplicity, we refer to both organismal and non-organismal characteristics as 'traits', although only the former are traits in the strict sense (Violle et al., 2007). The idea that certain organismal traits like body size or fecundity make species more susceptible to extinction is well-established (e.g., Cardillo et al., 2006; Pimm et al., 2006) and evidence also exists that non-organismal traits, such as niche breadth, correlate with species susceptibility to external pressures (Thuiller et al., 2005a; Williams et al., 2007). Recently, some authors identified a suite of traits that are likely to be related with the species intrinsic capacity to cope with environmental change (e.g., Angert et al., 2011; Foden et al., 2008, 2013; Jiguet et al. ,2007). For example, Foden et al. (2008) identified, as traits that are likely to relate to species susceptibility to climate change, degree of specialization to habitat requirements or degree of tolerance to environmental variation. In a more specific study, Jiguet et al. (2007) found that the species characteristics associated with population declines of birds in France during a time period with climate change were: low ecological tolerance, low heat tolerance and small brood number.

The present study builds on previous studies that develop frameworks to assess the risks of global environmental change to species conservation (e.g., Crossman et al., 2012; Chin et al., 2010; Foden et al., 2013; Şekercioğlu et al., 2012; Thomas et al., 2011). However we go beyond simply combining different sources of information to derive an indicator of risk, as we also compare the risk as assessed by individual criterion and data types. This is important for identifying trade-offs between multiple stressors because it has been shown that the interactions between them can be non-additive (Darling and Côté, 2008; but see Hof et al., 2011). Moreover, ours is the first risk assessment, as far as we are aware, that includes simulated vegetation as covariate in the models providing future projections and this is important because species distributions are not at equilibrium with climate (Araújo and Pearson, 2005; Munguía et al., 2012) and responses are often mediated by lagged responses of vegetation (e.g., García-Valdés et al., 2013). Here, we examine the combined effects of exposure and vulnerability of Iberian bird species to environmental changes, focusing on their potential effects in distributions. The metric of vulnerability is obtained by combining traits related to species abilities to cope with environmental change and current threat status from IUCN listings (Eq. (1)).

$$\text{Risk} = \text{Exposure} + \text{Vulnerability}[\mathit{Sus.} * \mathit{Con.}] \tag{1}$$

where *Sus.* is the Susceptibility measured using traits and *Con.* is the contemporary conservation status.

Such combinatorial indices have several known problems for conservation prioritization (discussed by Williams and Araújo (2002)), but their careful use enables investigation of relevant patterns. Specifically, they allow us to address the following questions: (i) are species highly exposed to environmental changes also highly vulnerable to them in terms of traits?; (ii) are species highly exposed to environmental changes highly threatened according to IUCN?; (iii) are regions harbouring the greatest concentration of species highly exposed to environmental changes also the regions where susceptible and currently threatened species occur?

2. Material and methods

2.1. Species data and potential exposure to global change

We assessed the potential exposure of 168 breeding bird species to future climate change and land use change, including climatically-driven changes in vegetation in the Iberian Peninsula using present and future model projections from a previous study (Triviño et al., 2011). To quantify predicted range shifts, two ensemble forecasting methods, Random Forests (RF) and Boosted Regression Trees (BRT), were used. The consensus based on the mean of the probabilities from RF and BRT was used (Araújo and New, 2007; Marmion et al., 2009) and the True Skill Statistic (TSS) method was chosen to convert probability values into presence-absence data (for a review in threshold-methods in climate change studies see Nenzén and Araújo, 2011).

Combined distributions from the Spanish Atlas of Breeding Birds (Martí and del Moral, 2003) and from the Portuguese Atlas of Breeding Birds (Equipa Atlas, 2008) were taken from recent studies (Araújo et al., 2012, 2011b), reporting the presence and absence of bird species in 5923 10×10 km resolution grid cells. We assessed the potential exposure of bird species to changes in climate, land use and vegetation using present (period 1971–1990) and future (period 2051–2080) model projections (details in Appendix A).

Even though the Iberian Peninsula includes a wide range of environmental conditions (e.g., Benayas et al., 2002), non-analogue climates are projected to emerge by the end of the century in the warmest and driest parts of the Iberian Peninsula (Araújo et al., 2011a). Thus, there is a non-negligible risk that future range contractions of species predicted by environmental envelope models could be overestimated for southern Iberian species that also occur in drier and warmer parts of Northern Africa (Barbet-Massin et al., 2010; Thuiller et al., 2004). To assess the sensitivity of our results to this potential problem of overestimation, the analyses linking the different levels of exposure to vulnerability traits (using boxplots, Kruskal–Wallis and Wilcoxon tests) and to current conservation status (using bar plots and χ^2 tests) were revisited using two different datasets. Firstly, the analyses were repeated using a subset of the original data excluding species with North African breeding ranges. For the classification of breeding ranges we used the Palaearctic Breeding Birds Guide (Svensson et al., 2009). Secondly, the analyses were repeated using an independent dataset that includes models using the full Western Palaearctic distribution range as well as the ensemble forecast from five general circulation models and three emission scenarios (Barbet-Massin et al., 2010). Finally, we compared if the composition of bird species that are contracting in the Iberian Peninsula matches with the composition in adjacent Mediterranean countries (France, Greece and Italy). For that we used the results from Araújo et al. (2011a) that divided their future projections by individual European countries.

2.2. Traits data

We selected seven traits that are known to provide an indication of bird susceptibility to global change (Table 1). The data compilation was restricted to a subset of 94 passerine bird species from a total of 168 species available because one of the 'traits', habitat breadth, was only available for these species. Further details and justification on the selection of traits are included in Appendix B.

2.3. Contemporary conservation status data

The conservation status of a species was considered both at international and national levels because mismatches between national and international Red Lists have been reported (e.g., Marini and Garcia, 2005) and conservation efforts should target species that are threatened at both regional and global scales. We used three different Red Lists to define the number of threatened bird species in the Iberian Peninsula (including Vulnerable (VU), Endangered (EN) or Critically Endangered (CR) categories): the IUCN Red List of globally threatened species (4 species) from the IUCN webpage (www.iucnredlist.org); the Spanish Red List of nationally

Table 1
Bird traits and environmental characteristics used in this study as a proxy for susceptibility to environmental changes for 94 bird species. For further details see Appendix B.

Traits	Source of data	Sign[a]	Why it is included?
1. Mean n° of broods	www.enciclopediadelasaves.es	↓	Higher number of broods less mismatch with food peaks
2. Clutch size	www.enciclopediadelasaves.es	↓	Low reproductive rate more susceptible
3. Length	www.enciclopediadelasaves.es	↑	Measure of body size: bigger species are more susceptible
4. Habitat breadth	Extracted from Appendix I of the Spanish Breeding Atlas Martí and del Moral (2003)	↓	Habitat specialization
5. Climatic niche breadth	Methodology used described in Appendix B	↓	Environmental tolerance
6. Marginality	See Appendix B	↑	Environmental tolerance
7. Relative range size	See Appendix B	↓	Environmental tolerance

[a] The association to species susceptibility: 'arrows facing up' mean that the higher the trait values the higher the susceptibility and 'arrows facing down' are the other way around.

Table 2
Bird species included in different IUCN conservation status categories (excluding Data Deficient (DD) species) at national (Portugal ($N = 162$) and Spain ($N = 165$) and at global scale ($N = 168$).

Location	IUCN conservation category				
	CR	EN	VU	NT	LC
Portugal	12 (7.4%)	10 (6.2%)	16 (9.9%)	18 (11.1%)	106 (65.4%)
Spain	0 (0%)	8 (4.8%)	15 (9.1%)	12 (7.3%)	130 (78.8%)
Global	0 (0%)	1 (0.6%)	3 (1.8%)	5 (3%)	159 (94.6%)
Combined	8 (4.8%)	14 (8.3%)	22 (13.1%)	22 (13.1%)	102 (60.7%)

threatened species (23 species) (Madroño et al., 2004); and the Portuguese Red List (34 Species) (Cabral et al., 2005) (Table 2).

2.4. Data analyses

Bird species were classified into groups based on their potential level of exposure to global change. We followed the methodology used in the Spanish and Iberian Atlases of Climate Change Impacts on Biodiversity (Araújo et al., 2011b), which classifies species into four groups:

(i) "Expanding species": Percentage of potential area lost < 0.
(ii) "Stables species": 0 < Percentage of potential area lost < 30.
(iii) "Contracting species": 30 < Percentage of potential area lost < 70.
(iv) "Major contracting species": Percentage of potential area lost > 70.

The percentage of potential area lost was interpreted as a measure of potential exposure and was calculated as:

$$\text{Potential area lost} = (P_{t1} - P_{t2}) * 100/P_{t1} \tag{2}$$

where P_{t1} is the present potential area occupied by the species and P_{t2} is the future potential area occupied by the species.

For each group (contracting, stable and expanding), we calculated the fraction of bird species included in each of the IUCN categories on national and international levels. This analysis was done according to the different assessment levels (Spain, Portugal and Global), each separately and also combined together. To form this "combined index", the IUCN categories were given a numerical value (Least Concern or Near Threatened = 0; Vulnerable = 1; Endangered = 2; Critically Endangered = 3). Each species is given a value based on its IUCN categories, endemicity to the study area (1 for endemics, 0 for non) and then those values are summed up (further described in Rocha et al., 2009). For example, a species that is classified as Endangered at the national scale (2 points), Vulnerable at the global scale (1 point) and endemic to the Iberian Peninsula (1 point) would have a combined index value of 4 points.

A correlation-based Principal Component Analysis (PCA) was carried out to reduce dimensionality in the species traits database. We retained the first three principal components, all with eigenvalues greater than 1 and together explaining 65% of the variation in the data (details in Appendix C).

In order to link the different levels of (i) potential exposure to environmental changes, (ii) trait-based species susceptibility to these changes, and (iii) current conservation status, the following statistical analyses were carried out. The association between the potential level of exposure to global change and the traits (represented by the three principal components) was tested using a Kruskal–Wallis test. Then, the level of potential exposure was regressed against each of the three first principal components of the PCA, using an ordinary least-square regression (OLS). The most parsimonious model was selected as the one having the lowest AIC (Akaike information criteria). Additional analyses illustrating the relationship between different exposure groups (contracting, stable and expanding) and each individual trait were included in the Supplementary material (see Appendix D). Because species are linked by their evolutionary history, we checked whether exposure showed any phylogenetic signal that would prevent us from using traditional linear regression (Blomberg et al., 2003). We calculated the lambda metric, a maximum-likelihood-based measurement of phylogenetic signal (Pagel, 1999) using the molecular phylogeny at the species level available from Thuiller et al. (2011). This metric corresponds to a tree transformation parameter that gradually eliminates phylogenetic structure when varying from 1 to 0. Lambda transformation is performed by multiplying the off-diagonal elements of the variance/covariance matrix describing the tree topology and branch lengths. Lambda values of 1 correspond to a Brownian evolution whereas, at the other extreme, a lambda value of 0 corresponds with complete absence of phylogenetic structure (star-like phylogeny). The estimated lambda can be compared to zero by computing a likelihood ratio and comparing it to a chi-square distribution with one degree of freedom (Münkemüller et al., 2012). The lambda metric indicated that there was no significant phylogenetic signal in the exposure variable (lambda = 0.0001). The association between potential level of exposure to global change and the current conservation status was represented using bar plots and statistical differences tested with a χ^2 test.

To explore which regions of the Iberian Peninsula harbour the greatest concentration of species at risk (from the 168 breeding bird dataset) we used the Geographical Information System (GIS) software ArcGIS 9.2. (ESRI, 2006). The different components of risk: (i) species susceptibility to changes represented by the three principal components of the PCA; (ii) current level of threat represented by the IUCN conservation status and (iii) potential exposure to future environmental changes were spatially represented in maps of 10 km resolution.

We plotted the potential exposure to future global change against the species potential vulnerability for the subset of 94

Table 3
Eigenvectors of the correlation matrix. The eigenvectors chosen to characterize each principal component are highlighted in bold.

Trait	PC1	PC2	PC3
N° broods	−0.3335	0.2102	**0.5624**
Clutch size	0.0087	**0.5829**	−0.4785
Length	−0.0774	**−0.5798**	−0.4734
Habitat breadth	**−0.5206**	0.0146	0.0523
Climatic niche breadth	**−0.3743**	−0.4052	−0.1060
Marginality	0.2799	−0.3365	0.4651
Relative range size	**−0.6271**	0.0474	−0.0198

passerine species to identify species facing higher risk of local extinction. The potential vulnerability was the result of applying this formula:

$$\text{Potential vulnerability} = \frac{\left(\sum_{i=1}^{3} PCi * \lambda PCi\right) * \text{Current conversation status}}{\sum_{i=1}^{3} \lambda PCi} \quad (3)$$

where 'λ' is the eigenvalue of each principal component and 'Current conservation status' is equal to 'Combined conservation status' +1 (to avoid null values).

3. Results

The first axis of the PCA carried out on bird traits was negatively related to habitat breadth, climatic niche breadth and relative range size. These measures are all associated with environmental tolerance. The second component was positively related to clutch size and negatively related to body size. These measures are associated with fecundity (Böhning-Gaese et al., 2000). Finally, the third component was positively associated to the number of broods (Table 3). Consequently, higher values for PC1 were interpreted as being related to higher susceptibility to environmental changes, and for PC2 and PC3 the opposite was assumed.

Of the 168 breeding bird species modelled, 90 were projected to potentially expand in the Iberian Peninsula, 52 to remain stable, and 26 to contract. There was no bird species included in the category of "major contracting species". Of the subset of 49 bird species whose breeding range does not include North Africa the classification was: Expanding = 24, Stable = 16 and Contracting = 9. Of the 117 species from the independent dataset from Barbet-Massin and colleagues the analysis gave: Expanding = 44, Stable = 58 and Contracting = 15. The analysis of potential range shifts was used to examine whether the species that are more exposed to global change are the same as those identified as threatened by the IUCN Red List (Fig. 1; Fig. E.2; Fig. E.4). Another analysis for the subsets with complete trait data from the three datasets was carried out. For 94 passerine bird species results were: Expanding = 36, Stable = 38 and Contracting = 20. For the subset of 28 species whose distribution breeding range does not include North Africa the classification was: Expanding = 11, Stable = 10 and Contracting = 7. Finally, for the 64 species from Barbet-Massin and colleagues the results were: Expanding = 22, Stable = 34 and Contracting = 8. The analysis of potential range shifts restricted for the species with complete traits data was used to examine whether the species that are more exposed to global change are the same as those being identified as susceptible (Fig. 2; Fig. E.1; Fig. E.3). From the comparison of the composition of bird species that are contracting in the Iberian Peninsula with the composition in adjacent Mediterranean countries we obtained a match of 69.2% when comparing with France, 92.0% with Greece and 84.6% with Italy.

3.1. Are species more exposed to environmental changes also more vulnerable to them?

The three groups of bird species (expanding, stable and contracting) differed significantly in their traits, as summarized using the three principal components (Kruskal–Wallis test for PC1: $\chi^2 = 32.18$, df = 2, $p < 0.001$; for PC2: $\chi^2 = 7.05$, df = 2, $p < 0.05$ but for PC3 there were no significant differences: $\chi^2 = 0.17$, df = 2, $p > 0.05$). Expanding species were associated with traits (narrow habitat breadth, narrow climatic niche breadth and small range size; Table 3) that tend to render species more vulnerable to environmental changes (see Fig. 2: higher values of PC1 and lower values of PC2 and PC3). The differences between 'contracting' and 'stable' species were not significant (Wilcoxon test, $p < 0.05$) (Table 4), whereas significant differences were found between species in the 'stable' and 'expanding' groups for PC1 and PC2.

The pattern remained also true for the subset of species whose distribution breeding range does not include North Africa and also when considering the independent dataset from Barbet-Massin (although in this case, the differences were not significant anymore) (Appendix E).

The OLS model relating the level of environmental exposure to the principal components and having the lowest AIC was the full model (Table 5). However, for the subset of species whose breeding range does not include North Africa the model having the lowest AIC was the PC1 and for the subset of species from the independent dataset of Barbet-Massin and colleagues the model with the lowest AIC was the PC3 (see Tables E.1. and E.2). The inclusion of second order polynomial of explanatory variables to account for potential nonlinear relationships did not decrease the AIC values, so we reported results only from the linear fits.

3.2. Are species highly exposed to environmental changes highly threatened according to IUCN?

Species less exposed to global change in the Iberian Peninsula (expanding) tend to be also the most threatened according to the IUCN criteria (Fig. 1). There was a significant difference between expanding species, which are currently more threatened, and stable species, which are less threatened (χ^2 test, $p < 0.001$), as well as between expanding (more threatened) and contracting species (less threatened) (χ^2 test, $p < 0.001$). However, there were no differences in threat category between contracting and stable species (χ^2 test, $p = 0.104$).

The pattern was also consistent for the subset of species whose breeding range do not include North Africa as well as for the independent dataset from Barbet-Massin that include models using the full Western Palaearctic distribution (Appendix E).

3.3. Are regions harbouring the greatest concentration of species highly exposed to environmental changes also the regions where susceptible and threatened species occur?

Regions harbouring large concentrations of species at risk differed based on the source of information used. Based on the environmental envelope models, the species more exposed to expected global change, i.e., the species potentially contracting their ranges, were mainly located in north-west of the Iberian Peninsula, whereas the expanding species were located in dry and warm areas in the south (Fig. 3E and F). However, results using traits indicated a different spatial pattern. Results indicate that the most vulnerable species, as measured through their environmental tolerances, are concentrated in the northern mountains of the Iberian Peninsula (Pyrenees and Cantabrian Mountains). But the most vulnerable species, as measured through fecundity traits, are located in the Mediterranean region, which occupies most part of

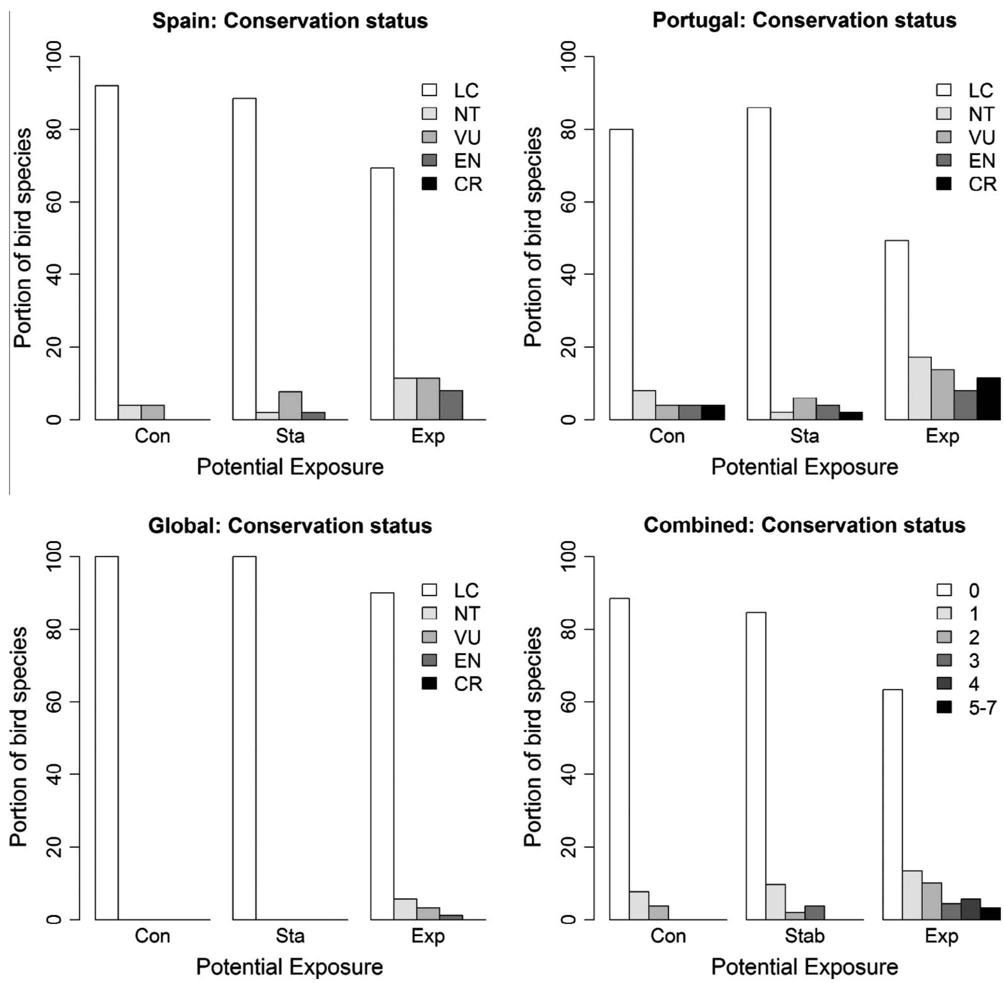

Fig. 1. Bar plots comparing the distribution of the IUCN conservation status (LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered and CR = Critical Endangered) and the combined conservation status (for Portugal, Spain and Global according to the method proposed by Rocha et al., 2009) among the three groups of species: "Con": Contracting (*N* = 26), "Sta": Stables (*N* = 52) and "Exp": Expanding (*N* = 90) for the 168 bird species considered.

the Peninsula except the north and the north-west. Values from the third principal component showed that the most vulnerable species are concentrated in the northern region of the Iberian Peninsula (Fig. 3A–C). The highest concentration of currently threatened species is located in flat and lowland areas which are dominated by croplands (Fig. 3D).

4. Discussion

Our study shows that risk assessments that combine both estimates of species exposure to environmental changes and metrics reflecting species intrinsic ability to persist in the face of environmental change provide different, and potentially, less pessimistic view of risks, for contracting species, when compared with evaluations that solely estimate risks from the degree of exposure to environmental change. Specifically, our results show that species expected to be highly exposed to future global environmental changes are currently less threatened and possess traits that render them less vulnerable than the less exposed species. However, our analyses also reveal that a large proportion of the species that are not currently threatened could become threatened in the future as a result of climate, vegetation, and land use changes (Fig. 1). Results are contingent on the particular group of species and region studied, but they highlight that coincidence between exposure to a threat and vulnerability to it cannot be taken for granted.

Conservation prioritization often focuses on areas with high species richness and great concentrations of endemic or threatened species (Myers et al., 2000). Alternatively, more sophisticated approaches can be used that maximize species conservation targets with complementarity-based algorithms (e.g., Margules et al., 1988; Williams et al., 1996). Our results support other studies that concluded that neither strategies would be sufficient to tackle the challenges brought by global environmental changes (e.g., Araújo et al., 2004; Hannah et al., 2007; Huey et al., 2012; Lee and Jetz, 2008). More specifically, in our study area, focusing conservation on areas with high species richness would lead to overlooking areas with high exposure to future threats and/or high concentrations of vulnerable species (e.g., Cardillo et al., 2006). Results in our study are consistent with those of previous studies showing the importance of integrating independent sources of information as focusing on just one component can under or over-estimate risk (e.g., Bellard et al., 2012; Foden et al., 2013). For instance, the consideration of physiological and behavioural responses, as well as the genetic and plastic capacity of species, might also provide lower estimates of local extinction risk. On the other hand, the inclusion of factors such as co-extinction, synergies and tipping points are expected to increase the estimates (Bellard et al., 2012). For example, a previous study with vertebrates in Europe (Araújo

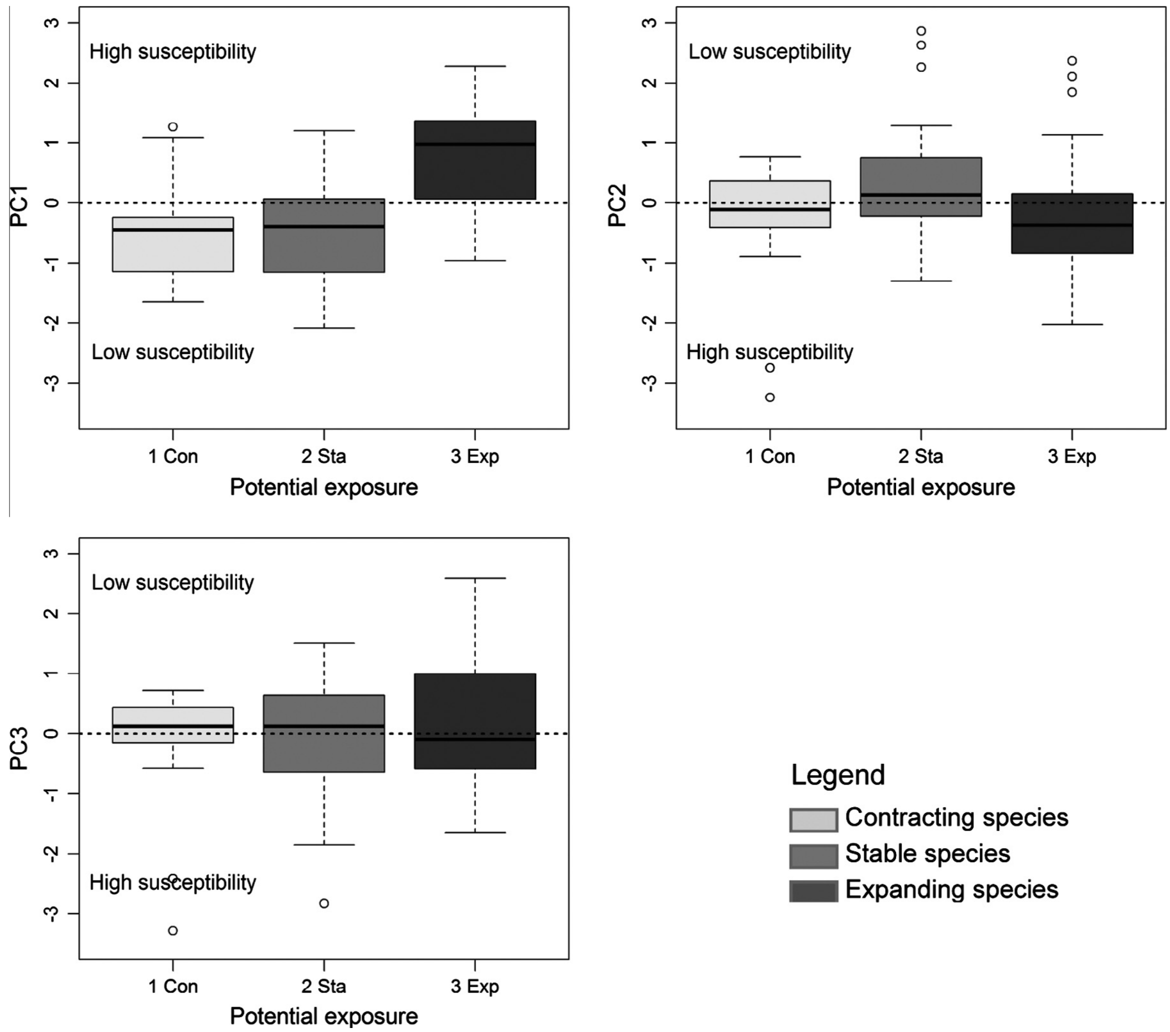

Fig. 2. Boxplots comparing traits of three groups of bird species based on their potential exposure to future environmental change ("1 Con": contracting species, "2 Sta": stables species and "3 Exp": expanding species). The traits were summarized using each of the three principal components axes (PC1, PC2 and PC3) respectively (see methods).

Table 4
Results of pair wise Wilcoxon test of distribution of the traits in the three different groups ("Con": Contracting species ($N = 20$), "Sta": Stable species ($N = 38$) and "Exp": Expanding species ($N = 36$)).

Principal component 1			Principal component 2			Principal component 3		
Con-Sta	Sta-Exp***	Con-Exp***	Con-Sta	Sta-Exp**	Con-Exp	Con-Sta	Sta-Exp	Con-Exp
$W = 373$ $p = 0.83$	$W = 1154$ $p = 7.5e{-}08$	$W = 646$ $p = 4e{-}06$	$W = 447$ $p = 0.14$	$W = 447$ $p = 0.0099$	$W = 322$ $p = 0.35$	$W = 373$ $p = 0.83$	$W = 731$ $p = 0.617$	$W = 387$ $p = 0.916$

** $= p < 0.01$.
*** $= p < 0.001$.

et al., 2011c) showed that species highly exposed to climate change were often poorly connected in a modelled network of species interactions and therefore they were less likely to be important for the stability of interaction networks.

Once species are categorized based on their potential risk to global change, how should such information be accounted for in processes leading to location and allocation of conservation resources? Advocates of triage, the process of prioritising the allocation of limited resources to maximise conservation returns, suggest that the management of species must be based on concepts of cost-efficiency (e.g., Bottrill et al., 2008; Myers, 1979; Wilson et al., 2011). Opponents of triage argue that the philosophical and functional consequences of letting threatened species go extinct cannot be afforded (e.g., Jachowski and Kesler, 2009; Pimm, 2000). We propose that species classification based on exposure and vulnerability can be a useful first assessment to help inform a triage process. Species categorization, when based on multivariate assessments of vulnerability, can be used to identify conservation actions that are appropriate for the specific threats faced by the species (see also Given and Norton, 1993). In some cases, proactive conservation (prioritizing areas with low risk) might be suitable, whereas in other cases reactive conservation (prioritizing areas

Table 5
Set of ordinary least square regressions to relate the level of environmental exposure with the three first principal components of the PCA for 94 bird species in the Iberian Peninsula. Res. Deviance: Residual deviance; DF: degrees of freedom; AIC: Akaike information criterion.

Variable	AIC	Res. Deviance	D^2	DF	Pr(>|t|)
PC1	1129.9	857409	21.98%	92	1.88e-06***
PC2	1151.8	1082382	1.51%	92	0.2382
PC3	1147.4	1033134	5.99%	92	0.0174*
PC1 + PC2	1128.4	808618	26.42%	90	0.0615
PC1 + PC3	1112.5	682704	37.88%	90	0.00027***
PC2 + PC3	1140.7	921682	16.13%	90	0.003**
PC1 + PC2 + PC3	1105.5	582315	47.01%	86	0.00076***

* $=p < 0.05$.
** $=p < 0.01$.
*** $=p < 0.001$; Null Deviance: 1098968.

with high risk) might be the socially accepted solution (Brooks et al., 2006). For example, following the conceptual scheme in Fig. 4, in line with the irreplaceability/vulnerability framework proposed by Margules and Pressey (2000), one could argue that no conservation actions are needed for species in the 'green area'. Furthermore, species located in the 'yellow area' are already identified as threatened, implying that some conservation actions are already taking place. Although many of these species may still require more conservation investment and effort than is currently achieved as current conservation effort has not been sufficient to halt biodiversity loss (e.g., Butchart et al., 2010). Species located in the 'orange area' are probably not the object of conservation actions yet, but may need them in the future. Therefore, monitoring schemes and proactive conservation tools designed to address threats from global change are needed for these species. Finally, there were few species located in the 'red area', threatened at the same time both by high potential exposure to environmental changes and high vulnerability to them (see also Tables F.1 and F.2 in Appendix F). This reduced group of species have large body sizes (e.g., Carrion crow *Corvus corone*), or are located in northern and mountainous areas (e.g., White-winged snowfinch *Anthus spinoletta*) or both. This explains that the Red-billed chough (*Pyrrhocorax pyrrhocorax*), a large body size and high mountain species, had the highest potential vulnerability (table D.3 in Appendix D). Moreover, there is evidence that several corvids are more vulnerable to temperature changes because they struggle to thermo-regulate and are directly limited by temperature

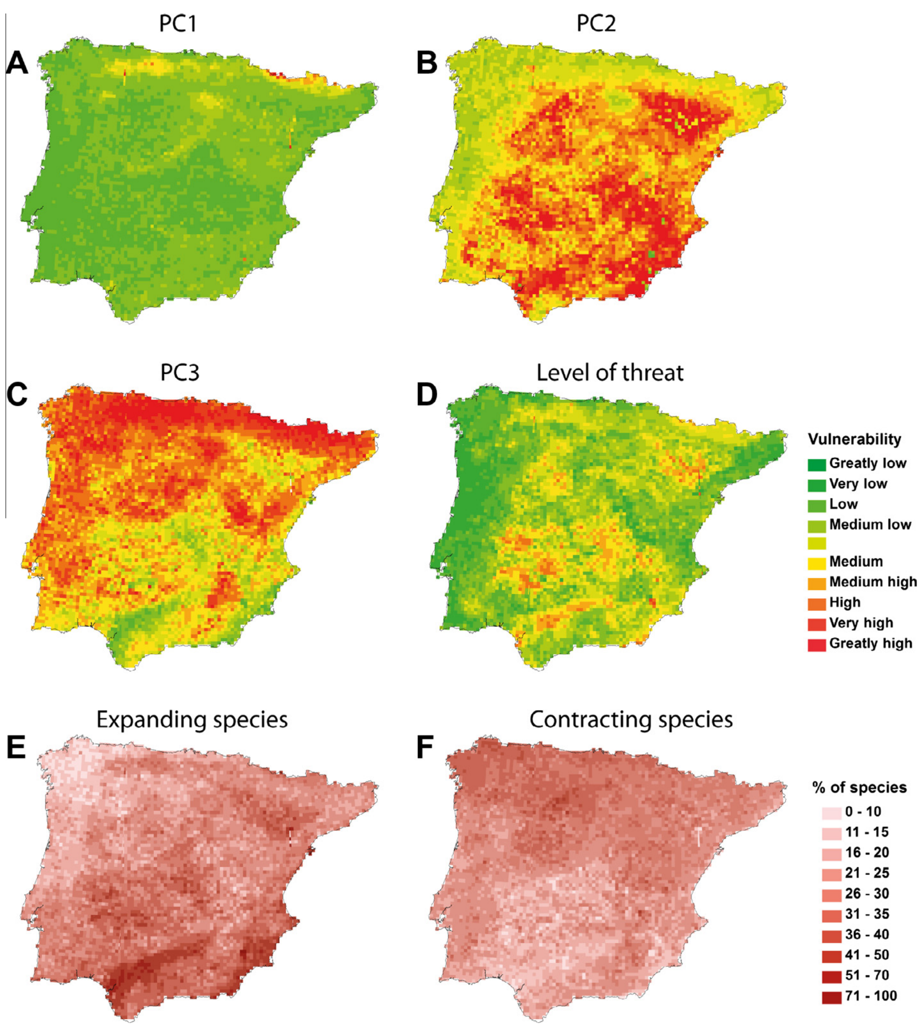

Fig. 3. Spatial patterns of risk. The maps A, B and C represent the mean values of PC1, PC2 and PC3 respectively for the total number of bird species ($N = 94$) occurring in each 10 km cell. The colour scale of PC2 and PC3 were inverted to match the PC1 scale. The original numerical scale (ranging from −2.44 to 0.42) was converted to a categorical scale to express the level of vulnerability in each 10 km cell. Map D represents the mean 'combined' conservation status of the species present in the cell. The original numerical scale (ranging from 0 to 9) was converted to the same categorical scale as PCA maps. Finally, the maps E and F represent the proportion of expanding ($N = 36$) and contracting ($N = 20$) bird species respectively in each 10 km cell. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

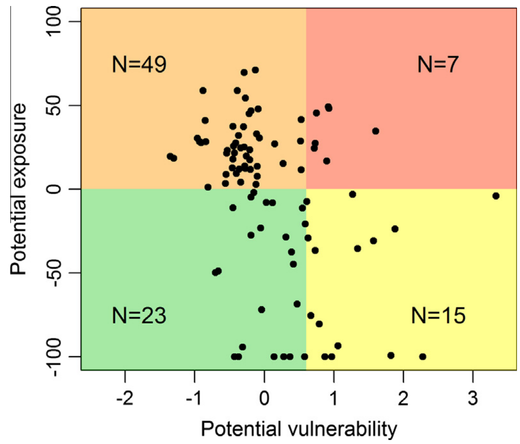

Fig. 4. Risk plot. The values of potential exposure to global change were plotted against the potential vulnerability for the subset of 94 species. The potential vulnerability was calculated multiplying the values from the PCA (species traits) with the combined conservation status and the third quartile was used as a splitting point. The potential exposure axis was divided, following the methodology used in Araújo et al. (2011a) into values below zero (including the expanding species) and values above zero (including the contracting and stable species). The 'green area' is occupied by species expected to expand their future ranges and that have low vulnerability. The 'yellow area' depicts regions with species already threatened that are not expected to be exposed to future threats. The 'orange area' is represented by species not yet threatened but that might become threatened in the future due to climate, vegetation and/or land use changes. Finally, the 'red area' is where species are highly exposed and highly vulnerable. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Donald et al., 2012; Hayworth and Weathers, 1984; Kelly et al., 2004). Conservation efforts should concentrate on species most at risk. In addition, it is worth noting that strategies proposed to face climate change (Heller and Zavaleta, 2009) should be better linked to the combinations of risks identified for different locations.

5. Conclusions

We identified Iberian bird species expected to be highly exposed and vulnerable to global environmental changes and found few species threatened at the same time by both risk estimates. Therefore, these different sources of information are complementary and diverse management strategies can be proposed depending on the source of risk. Identifying species likely to become highly threatened in the future is important for priority setting in conservation, especially as declines are hard to stop once underway. Moreover, determining species ability to persist under future threats could complement other criteria to include species in the Red list status and offer an alternative to conservation plans focusing only on species experiencing high current risk of extinction.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2013.10.005.

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