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From climate change predictions to actions – conserving vulnerable animal groups in hotspots at a regional scale.



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Abstract:	Current climate change is a major threat to biodiversity. Species unable to adapt or move will face local or global extinction and this is more likely to happen to species with narrow climatic and habitat requirements and limited dispersal abilities, such as amphibians and reptiles. Biodiversity losses are likely to be greatest in global biodiversity hotspots where climate change is fast, such as the Iberian Peninsula. Here we assess the impact of climate change on 37 endemic and nearly endemic herptiles of the Iberian Peninsula by predicting species distributions for three different times into the future (2020, 2050 and 2080) using an ensemble of bioclimatic models and different combinations of species dispersal ability, emission levels and global circulation models. Our results show that species with Atlantic affinities that occur mainly in the North-western Iberian Peninsula have severely reduced future distributions. Up to 13 species may lose their entire potential distribution by 2080. Furthermore, our analysis indicates that the most critical period for the majority of these species will be the next decade. While there is considerable variability between the scenarios we believe that our results provide a robust relative evaluation of climate change impacts among different species. Future evaluation of the vulnerability of individual species to climate change should account for their adaptive capacity to climate change, including factors such as physiological climate tolerance,

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	geographical range size, local abundance, life cycle, behavioural and phenological adaptability, evolutionary potential and dispersal ability.



For Review Only

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8 3 hotspots at a regional scale.
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58
59 24 **Key words:** amphibians, reptiles, climate change, Iberian Peninsula, ensemble modelling,
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25 species distribution model, vulnerability, adaptive management

Abstract

Current climate change is a major threat to biodiversity. Species unable to adapt or move will face local or global extinction and this is more likely to happen to species with narrow climatic and habitat requirements and limited dispersal abilities, such as amphibians and reptiles. Biodiversity losses are likely to be greatest in global biodiversity hotspots where climate change is fast, such as the Iberian Peninsula. Here we assess the impact of climate change on 37 endemic and nearly endemic herptiles of the Iberian Peninsula by predicting species distributions for three different times into the future (2020, 2050 and 2080) using an ensemble of bioclimatic models and different combinations of species dispersal ability, emission levels and global circulation models. Our results show that species with Atlantic affinities that occur mainly in the North-western Iberian Peninsula have severely reduced future distributions. Up to 13 species may lose their entire potential distribution by 2080. Furthermore, our analysis indicates that the most critical period for the majority of these species will be the next decade. While there is considerable variability between the scenarios we believe that our results provide a robust relative evaluation of climate change impacts among different species. Future evaluation of the vulnerability of individual species to climate change should account for their adaptive capacity to climate change, including factors such as physiological climate tolerance, geographical range size, local abundance, life cycle, behavioural and phenological adaptability, evolutionary potential and dispersal ability.

45 Introduction

46 Anthropogenic driven climate change is evident and for the next two decades a warming of at
47 least 0.2°C per decade is projected (IPCC, 2007) with associated changes in precipitation
48 patterns. Throughout the history of Earth, climate has changed and species have coped and
49 adapted to these changes, but current climate change is threatening biodiversity because it is
50 fast compared to most past changes (Thomas *et al.*, 2004). Current climate warming was
51 considered the second most important threat to terrestrial biodiversity, only exceeded by
52 land-use change (Sala *et al.*, 2000).

53 Climate change have been reported to affect many aspects of populations: physiology,
54 distribution, phenology, behaviour and propensity for local extinction (Hughes, 2000,
55 Walther *et al.*, 2002, McCarty, 2002, Root *et al.*, 2003, Parmesan, 2006). Species may be able
56 to adapt to climatic changes via ecological (Root *et al.*, 2005) or evolutionary processes
57 (Bradshaw *et al.*, 2006, Skelly *et al.*, 2007). However, species unable to achieve a sufficient
58 level of adaptation will likely face local or global extinction and this is more likely to happen
59 to species with restricted climate and habitat requirements, limited dispersal abilities and
60 ectothermal physiology (Walther *et al.*, 2002, Thomas *et al.*, 2004, Massot *et al.*, 2008).

61 Amphibians and reptiles are considered one of the most vulnerable taxonomic groups to
62 climate change (Gibbons *et al.*, 2000, Carey *et al.*, 2003, Araújo *et al.*, 2006, Wake, 2007).

63 Climate warming is projected to induce a) changes in abundance; b) fragmentation of suitable
64 habitats; c) changes in the timing of life-cycle events, such as hibernation, aestivation and
65 breeding (Blaustein *et al.*, 2001, Chadwick *et al.*, 2006) and d) the spread of agents of
66 infectious diseases such as the chytridiomycete fungus (Pounds *et al.*, 2006, Bosch *et al.*,
67 2007, Wake, 2007). The interaction of these impacts causes disruptions in population and
68 metapopulations dynamics, which ultimately may lead to changes in distribution.

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3 69 The impact of global warming on biodiversity is likely to be more severe in regions rich in
4
5 70 endemic species that are also predicted to be affected by dramatic climatic changes. The
6
7
8 71 Mediterranean Basin is a particularly susceptible region: it is a biodiversity hotspot holding
9
10 72 many endemic species (Médail *et al.*, 1999, Myers *et al.*, 2000, Mittermeier *et al.* 2005) and
11
12 73 climate predictions for this region include a substantial rise in temperature and a drastic drop
13
14
15 74 in rainfall, contributing to desertification (MIO-ECSDE, 2003). The synergistic effect of
16
17 75 climate change with other threats to biodiversity makes this region one of the most vulnerable
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19
20 76 in the world (Sala *et al.*, 2000).

21
22 77 The Iberian Peninsula, in particular, is a Mediterranean sub-region with many endemic
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25 78 species. The high biodiversity derives from the fact that this area was one of the major glacial
26
27 79 refugia in Europe during the Pleistocene (Hewitt, 1996) and a diversification centre
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30 80 afterwards (Gómez *et al.*, 2006, Pinho *et al.*, 2007). Biodiversity richness in this area is also
31
32 81 influenced by the climatic heterogeneity, since the climate transition between Atlantic and
33
34 82 Mediterranean allows the co-occurrence of species with African and Euro-Siberian affinities,
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36
37 83 which means that the Iberian Peninsula is a biogeographic crossroad (Spector, 2002).

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40 84 In face of climate change challenges, conservation organizations are being asked to take
41
42 85 proactive measures to mitigate impacts on biodiversity. To select appropriate measures we
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44
45 86 need to be able to predict the impact of climate change on biodiversity and evaluate the
46
47 87 ability of biodiversity to adapt to those impacts. The combination of this information can be
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49
50 88 used to determine biodiversity vulnerability, which in turn becomes the basis for prioritizing
51
52 89 species and defining management strategies (Kareiva *et al.*, 2008).

53
54 90 Species distribution models (SDMs) are frequently used to assess the impacts of climate
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56
57 91 change on species distributions (*e.g.* Araújo *et al.*, 2006). These statistical tools relate present
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60 92 day distributions with current environmental conditions and then use future potential climate
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94 93 conditions to predict future species distributions (Pearson *et al.*, 2003). Predicting the impacts

1
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3 94 of climate change on species is a challenging task because SDMs include parameters with
4
5 95 many sources of uncertainty (Webster *et al.*, 2002) mostly related to: a) the statistical tool
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8 96 used for modelling species distributions; b) the global circulation models used to predict
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10 97 future climate conditions (Thuiller, 2004, Pearson *et al.*, 2006, Beaumont *et al.*, 2008); and c)
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12 98 uncertainty derived from scale effects (Seo *et al.*, 2009). Recently, advances in SDMs have
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14
15 99 made it possible to significantly reduce prediction uncertainties. For example, several robust
16
17 100 statistical modelling methods have been developed to predict species distributions (see Elith
18
19 101 *et al.*, 2006 for review), while advanced methodologies in ensemble forecasting allow us to
20
21 102 overcome the problem of variability in predictions made by different modelling techniques or
22
23 103 different global circulation models (Pearson *et al.*, 2006, Araújo *et al.*, 2007, Marmion *et al.*,
24
25 104 2009). Additionally, climate predictions have been improved at smaller spatial scales
26
27 105 (Hijmans *et al.*, 2005).

31
32 106 In this study, we will evaluate potential impacts of climate change on the distribution of
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34 107 amphibians and reptiles in the Iberian Peninsula. We focus on endemic and nearly endemic
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36 108 species, the later defined as species that have approximately more than two thirds of their
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38 109 entire range in the Iberian Peninsula. We then use information about species adaptability and
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40 110 vulnerability to make conservation recommendations.

43
44 111 Araújo *et al.* (2006) identified the Iberian Peninsula as one of the areas in Europe where
45
46 112 amphibians and reptiles are likely to undergo major contractions in their ranges. Therefore, a
47
48 113 detailed analysis of the Iberian Peninsula at a scale appropriate for establishing management
49
50 114 strategies is urgently needed. We complement Araújo *et al.*'s (2006) European-wide research
51
52 115 by providing a more detailed analysis of the impact of climate change on amphibian and
53
54 116 reptile's distribution within the Iberian Peninsula. In particular, we used the most recent
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56 117 distribution data which are geographically more detailed than the one used in Araújo *et al.*
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58 118 (2006) (10x10 km in opposition to 50x50km) and incorporate recent taxonomic discoveries,
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3 119 that significantly increases the number of endemics (21 species vs. 12 species). Additionally,
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5 120 we project species ranges to three times in the future (2020, 2050, 2080 instead of 2050
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7
8 121 only), which may assist conservation decision making in terms of prioritizing the allocation
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10 122 of conservation funds through time.

11
12 123 We provide specific recommendations to conservation practitioners for enhancing the
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14 124 probability of species persistence by answering the following questions: In the Iberian
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16 125 Peninsula, which endemic and nearly endemic amphibian and reptile species are predicted to
17
18 126 lose and gain suitable habitat in the future? For species predicted to lose suitable habitat, is
19
20 127 the loss rate constant throughout time or are there more critical periods? Which areas will be
21
22 128 more impacted by species loss? Which species should be under priority conservation action?
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24 129 Which conservation measures are most likely to increase the probability of species
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26 130 persistence?
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34 132 **Methods**

35 36 37 133 *Study area*

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39 134 The study region is the continental Iberian Peninsula, situated in the extreme southwest of
40
41 135 Europe (bounded by 9°32' to 3°20'E and 35°56' to 43°55'N). With an area of 582 860 km², it
42
43 136 includes the continental territories of Portugal and Spain. It is bordered to the south and east
44
45 137 by the Mediterranean Sea and to the north and west by the Atlantic Ocean. The Pyrenees and
46
47 138 the Strait of Gibraltar separate most of the region from the remainder of Europe and Africa,
48
49 139 respectively (Figure 1). The dominant climate type of the region is Mediterranean, but the
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51 140 north and northwest of the Iberian Peninsula and the major mountain systems are
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53 141 characterised by an Atlantic climate.
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143 *Species and distribution data*

1
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3 144 Distribution data for 37 endemic and nearly endemic species (15 amphibians and 22 reptiles)
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5 145 were collected from the most recent herpetological atlases of Portugal (Loureiro *et al.*, 2008)
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8 146 and Spain (Pleguezuelos *et al.*, 2002), which are referenced to the UTM grid of 10x10 km.
9
10 147 Taxonomy was defined according to the most recent revision of the taxonomic list in
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12 148 Carretero *et al.* (2009). We excluded from our analysis records from the Portuguese atlas for
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14 149 *Triturus marmoratus* because that data does not distinguish between *Triturus marmoratus*
15
16 150 and *T. pygmaeus*. We followed the same method for Portuguese records of *Pelodytes*
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18 151 *punctatus* because they represent two species: *Pelodytes punctatus* and *P. ibericus*. Our data
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20 152 contained only two records of *Iberolacerta martinezricai* so we were unable to develop a
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22 153 plausible predictive model.
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30 ***Climate data***

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33 156 Current bioclimatic data were downloaded from WorldClim database (Hijmans *et al.*, 2005)
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35 157 which is a set of global climate layers generated through interpolation of climate data from
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37 158 weather stations. We used nine variables that were not tightly correlated with each other
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39 159 (with a Pearson correlation coefficient between them lower than 0.75): temperature
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41 160 seasonality, maximum temperature of warmest month, minimum temperature of coldest
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43 161 month, temperature annual range, annual precipitation, precipitation of wettest month,
44
45 162 precipitation of driest month, precipitation seasonality and altitude. All variables were
46
47 163 downloaded in a 2.5 arc-minute resolution. We converted these data to match with the same
48
49 164 grid format as the species distribution data by averaging the variable's values inside each grid
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51 165 cell.
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57 166 We used future climate data for three Global Circulation Models (GCM) (CCCMA,
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59 167 HADCM3 and CSIRO) and two IPCC 3rd assessment storylines (A2 and B2). The IPCC
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168 storylines describe the relationships between the forces driving greenhouse gas and aerosol

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3 169 emissions such as demographic, social, economic, technological, and environmental
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5 170 developments (IPCC-TGICA, 2007). The two storylines used for this study assume
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8 171 regionally oriented economic growth, with population and economic growth being higher in
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10 172 A2 than B2. Future climate data were downloaded from WorldClim, for three different future
11
12 173 years (2020, 2050 and 2080) creating six storyline-GCM combinations for each future year.
14
15 174 We downloaded monthly averages of maximum and minimum temperatures and total
16
17 175 precipitation and calculated the bioclimatic variables according to the same methodology
18
19 176 used to calculate them for current climate conditions (Hijmans *et al.*, 2005).
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25 178 ***Species distributions: current predictions and future projections***

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27
28 179 We used a set of nine modelling techniques to predict the distribution of each of the 37
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30 180 species in four different times (current, 2020, 2050 and 2080): Maximum Entropy (MXT),
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32 181 Generalised Linear Models (GLM), Generalised Additive Models (GAM), Classification
33
34 182 Tree Analysis (CTE), Artificial Neural Networks (ANN), Generalised Boosting Model
35
36 183 (GBM), Breiman and Cutler's random forest for classification and regression (RF), Mixture
37
38 184 Discriminant Analysis (MDS) and Multiple Adaptive Regression Splines (MARS).
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43 185 To produce Maximum Entropy models we used Maxent software (Phillips *et al.*, 2004).
44
45 186 Maxent estimates the range of a species with the constraint that the expected value of each
46
47 187 variable (or its transform and/or interactions) should match its empirical average, *i.e.* the
48
49 188 average value for a set of sample points taken from the species-target distribution (Phillips *et*
50
51 189 *al.*, 2006, Phillips *et al.*, 2008). We used the default “auto features” option, logistic output,
52
53 190 the recommended default values for the convergence threshold (10^{-5}) and the maximum
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55 191 number of iterations (500).
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3 192 The remaining eight models were built within BIOMOD (Thuiller *et al.*, 2009) . BIOMOD is
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5 193 a collection of functions running within the R software v. 2.8.1 (R Development Core Team
6
7 194 2008) for ensemble forecasting of species distributions and a summary of model statistics is
8
9 195 described in Thuiller *et al.*, (2009). The majority of model-techniques requires data about
10
11 196 presences and absences, thus we determined pseudo-absences for each species by using the
12
13 197 “random strategy” in BIOMOD. The number of selected pseudo-absences for each species
14
15 198 was equal to the number of its occurrences, whenever possible. In cases where the number of
16
17 199 locations where species was not recorded was less than the number of occurrences, we
18
19 200 selected all non-occurrences as pseudo-absences. All models were produced using default
20
21 201 BIOMOD parameters where possible (Thuiller *et al.*, 2009). Further parameters were as
22
23 202 following: GLMs were generated using quadratic terms and a stepwise procedure with the
24
25 203 AIC criteria. GAMs were generated with a spline function with 4 degrees of smoothing.
26
27 204 ANNs were produced with two cross-validations. BIOMOD allows evaluation of model
28
29 205 performance on different data split runs and then allows using 100% of the data to make a
30
31 206 final calibration of the models for prediction. Thus we randomly assigned 80% of occurrence
32
33 207 data to train the model with the remaining 20% for testing. Each model was run ten times to
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35 208 avoid bias resulting from randomly splitting the data into training and testing.
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44 209 To evaluate the performance of individual models from each technique, we calculated the
45
46 210 area under the receiver operating characteristic curve (AUC) (Zweig *et al.*, 1993, Fielding *et*
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48 211 *al.*, 1997). For each of the 37 species we produced nine models for the current time and
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50 212 climate (with different modelling techniques) and 54 models (combination of nine modelling
51
52 213 techniques, three GCM and two storylines) for each of the three times in the future (2020,
53
54 214 2050 and 2080), in a total of 171 models per species.
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56
57

58 215 For each year in the future (2020, 2050 and 2080) we calculated an ensemble forecast for
59
60 216 current time and for each IPCC scenario for the future (A2, and B2). For this purpose, we

217 used weighted average consensus method based on AUC values, because this method is
 218 considered to significantly improve the predictive accuracy of single models (Marmion *et al.*,
 219 2009). Thus, AUCs values of each model technique were assigned the weights of the
 220 weighted average in order to enhance contributions of those models with higher model
 221 performance values (equation 1).

222

$$WA_i = \frac{\sum_m (AUC_m \times p_{mi})}{\sum_m AUC_m} \quad (\text{equation 1})$$

224 where i is the index of the grid cell, m is the model technique and p is the probability of
 225 occurrence of the species (according to model m in grid cell i).

226 To investigate if species ranges were predicted to contract or expand, we needed to convert
 227 the consensus forecasted probabilities of occurrence in each year to a binary value of
 228 predicted presence/absence. For each model technique, we calculated the threshold of the
 229 receiver operating characteristic curve that maximizes both correctly predicted presences and
 230 absences, relative to the evaluation data (Liu *et al.*, 2005). Subsequently, we determined a
 231 consensus threshold (CT) by calculating the weighted average threshold, assigning the AUC
 232 value of each model as a weight (equation 2).

233

$$CT = \frac{\sum_m (AUC_m \times t_m)}{\sum_m AUC_m} \quad (\text{equation 2})$$

235 where m is the model technique and t_m is the optimised threshold of model m .

236 Potential range shifts of each species and time period were measured under two extreme
 237 dispersion scenarios: unlimited dispersal (scenario D), assuming that species can disperse to

1
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3 238 any grid cell with suitable habitat, and no dispersal (scenario ND), assuming that species are
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5 239 not capable to disperse even if suitable habitat is available. To predict species presence under
6
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8 240 the D scenario, we transformed the consensus probability value in each grid cell into 0 if it
9
10 241 was lower than CT and to 1 if it was equal to or higher than CT. To predict species presences
11
12 242 under the ND scenario, we transformed predicted presences to absences in grid cells where
13
14
15 243 species is not presently predicted to occur. We evaluated the degree of uncertainty of
16
17 244 projections for each year and scenario by calculating the standard deviation of predicted
18
19 245 occurrence of species by grid cell.

20
21
22 246 Subsequently, we calculated predicted species richness in each grid cell for the three future
23
24
25 247 periods. Future species richness was estimated by summing the number of species predicted
26
27 248 to occur in each grid cell under each of the storylines and the dispersion scenarios. Species
28
29 249 turnover (T) is the dissimilarity index between the present and future species composition of
30
31 250 a given area. It accounts both for species gain and losses and its relation to the overall number
32
33 251 of species occurring in the grid cell in present and future. Thus, a turnover value of 0
34
35 252 indicates that the predicted assemblage in the future would be the same as the current
36
37 253 assemblage, whereas a turnover value of 100 indicates that the assemblage would be
38
39 254 completely different under climate change. To determine it, we first calculated the number of
40
41 255 species lost (L), *i.e.*, the number of species predicted to lose suitable habitat in each grid cell,
42
43 256 and the species gain (G), *i.e.*, the number of species predicted to gain suitable habitat in each
44
45 257 grid cell. Percentage of species turnover by grid cell was then calculated according to
46
47 258 equation 3.

52
53
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55 259
$$T = 100 \times \frac{L + G}{SR + G},$$
 (equation 3)
56
57

58 260 where SR is the current predicted species richness.
59
60
261

262 **Results**

263 Model predictions within different modelling techniques, GCMs, and storylines showed high
264 variability in the projection of range shifts, with most species being projected to both lose and
265 gain suitable habitat, depending on the scenario (supplementary material A.1 and A.2).
266 However, when analysing the ensemble model results (Tables 1 and 2), we found that 46% of
267 the species are consistently predicted to have a smaller distribution in both storylines (9
268 amphibian species and 8 reptile species), 28% of the species are consistently predicted to
269 have a larger distribution (3 amphibian species and 8 reptile species) and the remaining
270 species show increases and decreases depending in the time period and storyline. For
271 example *Algyroides marchi* is predicted to have a smaller distribution until 2050 and then
272 increase its distribution by 2080, while, *Alytes cisternasii* and *Lissotriton boscai* are predicted
273 to have a larger distribution until 2020 and then have a smaller distribution.

274 Several species are predicted to lose a significant fraction of their current range (Figure 2)
275 and 10 species are predicted to lose their entire suitable distribution at some time in both
276 storylines. Three other species are predicted to lose all suitable range in one of the storylines
277 only (Table 3). Surprisingly 5 to 10 of the 13 species that are predicted to lose all their
278 suitable distribution lose it by 2020 (Table 3). Additionally, 9 of these species are also
279 threatened by other causes, and currently considered “critically endangered”, “endangered” or
280 “vulnerable”, in Portuguese or Spanish red data books (Tables 1 and 2).

281 If we assume that species have no ability to disperse, 34 species are predicted to contract their
282 distribution and 10 species are predicted to completely lose their entire distribution in both
283 storylines.

284 It is noteworthy that for species predicted to have a smaller distribution in the future, both the
285 magnitude of contraction and the rate of contraction differ between species (Figure 3). While
286 for most contracting species, the rate of range contraction is greater now (until 2020), for

1
2
3 287 some species there is almost a constant rate of predicted distribution loss (*e.g. Rana iberica*),
4
5 288 while for a minority of species the period of greatest contraction is later (*e.g. Psammodromus*
6
7 289 *algirus*).

8
9
10 290 Predicted patterns of species richness are substantially different between the two dispersion
11
12 291 scenarios, but higher species richness was commonly predicted in south-western Iberian
13
14 292 Peninsula, the Central System mountain range and Morena Mountains (Figures 4 and 5).
15
16 293 Major species gain, in the unlimited dispersion scenario, was predicted for the central
17
18 294 plateaus, the central-western coast of the Iberian Peninsula, and the Cantabrian Mountains
19
20 295 (Figure.6). Major loss of species ranges is predicted for the Atlantic climate regions, mostly
21
22 296 along the northwest of the Iberian Peninsula and the main mountain ranges, such as the
23
24 297 Central System and the Morena Mountains (Figure. 6). Spatial patterns of predicted species
25
26 298 richness are similar in both storylines, although storyline B2 predicted slightly higher species
27
28 299 losses for 2020 and storyline A2 predicted higher species loss for 2080 (Figures 4 and 5).
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38 301 **Discussion**

39 302 *Main findings and relation with previous projections*

40
41 303 Our results suggest that climate change might have serious impacts on the distribution
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43 304 patterns of the endemic and nearly endemic amphibians and reptiles of the Iberian Peninsula,
44
45 305 particularly for species with Atlantic climate affinities such as *Chioglossa lusitanica*, *Rana*
46
47 306 *iberica* and *Vipera seoanei* and particularly high altitude species with Atlantic climate
48
49 307 affinities such as, *Rana pyrenaica*, *Iberolacerta monticola*, *I. aranica*, *I. aurelioi*, and *I.*
50
51 308 *bonnali*. It is also possible that other species may be more affected by climate change than
52
53 309 predicted by the models, such as *Iberolacerta cyreni*. This species is an endemic with a
54
55 310 current range restricted to the Gredos Mountains in Spain. However, the ensemble model for
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3 311 this species predicted a current range much larger than probably the one where the species
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5 312 actually occurs. This indicates that predicted future range may also be overestimated. On the
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7
8 313 other side, models for *Pelodytes ibericus*, *Triturus marmoratus* and *T. pygmaeus* were built
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10 314 only based on Spanish records, although they also occur in Portugal. This methodological
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12 315 caveat may have conducted to an under estimation of current and future ranges of those
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15 316 species.

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17 317 Our analysis indicates that the most critical period for the majority of these species will be the
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19 318 next decade. This result emphasises the need for immediate conservation action in the Iberian
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21 319 Peninsula to ameliorate the impact of climate change.

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24 320 Previous macroscale studies have called attention to the vulnerability of biodiversity in the
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26 321 Mediterranean basin. This region was considered one of the most vulnerable in the world
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28 322 (Sala *et al.*, 2000) and one of the biodiversity hotspots likely to undergo major losses due to
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30 323 climate change, along with the Cape Floristic Region, the Caribbean, Indo-Burma, Southwest
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32 324 Australia, and the Tropical Andes (Malcolm *et al.*, 2006). The Iberian Peninsula is considered
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34 325 the Mediterranean sub-region most likely to be affected by future climate change (EEA,
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36 326 2004). Our analysis confirm the vulnerability of species occurring in the Iberian Peninsula to
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38 327 climate change, but curiously, species with Atlantic climate affinities were predicted to be
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40 328 more affected by climate change than the Mediterranean ones. The Atlantic climate region is
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42 329 much more restricted in the Iberian Peninsula than the Mediterranean. Due to predicted drops
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44 330 in precipitation and temperature raise it is likely that the all Iberia became dominated by a
45
46 331 Mediterranean climate. Thus, it seems logical that Atlantic species become more affected by
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48 332 climate change than the Mediterranean ones. Climate change impacts on Atlantic species was
49
50 333 exacerbated by the region being a peninsula so dispersal out of the region to other Atlantic
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52 334 climate regions is restricted. Similar patterns should be found in other Mediterranean
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54 335 Peninsulas that present different climatic types (*e.g.* the Italian Peninsula and the Balkans).

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3 336 Our results are consistent with those found by Araújo *et al.* (2006), in the sense that climate
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5 337 change is predicted to cause a major contraction in the distribution of a considerable number
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8 338 of amphibian and reptile species in the Iberian Peninsula. However, our results revealed that
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10 339 major losses for endemic and nearly endemic species will occur in substantially different
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12 340 areas than the ones predicted by Araújo *et al.* (2006) for the all amphibians and reptiles. We
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14
15 341 predict that the north-west of the region, the Central System and the Morena Mountains will
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17 342 lose many species in contrast to their results where there is expected to be species gain. The
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19 343 reasons for this difference may be our focus on endemic and nearly endemic species rather
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21 344 than all species, but it could also be differences in spatial scale or methods used to construct
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23 345 the ensemble models. Dissimilarities in areas predicted to gain species may also be related to
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25 346 the colonization of non endemic or nearly endemic species and non Iberian species not
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27 347 included in our analysis. These divergent results highlight the importance of finer-scale
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29 348 analyses for areas identified as vulnerable in broader continental-scale studies.
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36 350 Interestingly, a previous study of climate change threats to plant diversity in Europe (Thuiller
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38 351 *et al.*, 2005) also identified the Iberian Peninsula as one of the European regions likely to
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40 352 undergo major species loss. Garzón *et al.* (2008) identified the north and northwest of the
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42 353 Iberian Peninsula and the main mountain ranges, as the Iberian areas likely to have the
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44 354 highest tree species loss, which is partially coincident with our results. Thus, if changes in
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46 355 vegetation communities are also predicted, it means that amphibians and reptiles will face a
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48 356 synergistic impact of climate and habitat change, which ultimately will also be coupled with
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50 357 the impact of changes in biotic interactions resulting from changes in the community of
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52 358 species. These results also suggest that the impacts of climate change on species ranges might
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54 359 be similar across different biodiversity groups that occur in the same area, which calls for the
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56 360 need to evaluate possible climate change impacts on those groups.
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361

362 ***From predicted impacts (models) to vulnerability***

363 Our dramatic predictions should be interpreted with caution given all the uncertainties in the
364 process: the statistical methods used for modelling species distributions, the global circulation
365 models used to predict future climate conditions (*e.g.* Araújo *et al.*, 2007, Beaumont *et al.*,
366 2008), the scale of the analysis (Seo *et al.*, 2009), and specific dispersal abilities. Additionally
367 species distribution models disregard important biological parameters that ultimately are the
368 determinants of species capability to adapt to climate change.

369 Different modelling techniques, GCM and storylines provided fairly different results for the
370 number of predicted occurrences of a species. The ensemble methodology allows us to
371 distinguish the strongest signal emerging from the noise associated with different model
372 outputs but it is not immune from uncertainty. Taking uncertainty into account, for example
373 by using as an uncertainty measure the standard deviation of the total number of occurrences
374 predicted by the different models for each species (appendix 1A and A2), the most likely
375 impact of climate change will be on species whose ranges are predicted to contract more
376 (relatively to their current extent), or to become more restricted (considering their future
377 absolute extent) with less uncertainty. For example, analysing only the year 2020 projections
378 for storyline A2, species that fulfil both criteria are *Discoglossus galganoi* (considering the
379 species whose ranges are predicted to contract more) and *Iberolacerta aranica*, (considering
380 the species whose ranges are predicted to become more restricted or disappear).

381 The scale of analysis may also be a relevant limitation in determining the impact of climate
382 change, because the scale used does not account for microhabitat variability within sites. This
383 constraint is quite relevant in the case of amphibians and reptiles because they might find
384 suitable habitat, for instance, in small ponds, water tanks, below stones or underground
385 (Kearney *et al.*, 2009). Also, the scale of the analysis probably obscures altitudinal

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3 386 microclimatic gradients which might allow species to move towards future suitable habitats
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6 387 without the need to disperse long distances.
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9 388 Specific dispersal abilities may strongly determine the impacts of climate change on the
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11 389 future distribution of species. However, given that this parameter is difficult to determine for
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13 390 every species, we predicted future distributions under the assumptions of maximal and
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15 391 minimal possible dispersal ability for each species. We recognize that both of these
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17 392 assumptions are unrealistic, but they allow us to predict the largest and smallest possible
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19 393 future ranges. A more realistic prediction would probably be somewhere in the middle of
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21 394 these two extremes, but we cannot make an exact prediction with high level of certainty.
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25 395 Assuming these limitations we do not argue that species predicted to completely lose their
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27 396 distribution under our analysis will go extinct. Rather, we consider that the degree, the
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29 397 certainty and the time of predicted range contractions provides a relative measure of the
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31 398 magnitude of the impact of climate change on each species. Ultimately, the vulnerability of a
32
33 399 species to a given impact will depend also on the species resistance, *i.e.* the ability of a
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35 400 species to withstand an environmental perturbation, and resilience, *i.e.* the ability of a species
36
37 401 to adapt and recover from a perturbation (Isaac *et al.*, 2008, Williams *et al.*, 2008,). Thus,
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39 402 prioritizing species for management actions would require a further analysis of the specific
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41 403 factors that determine resistance and resilience. In general, the species traits that are predicted
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43 404 to promote species resistance to climate change are physiologic climatic tolerance (Calosi *et*
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45 405 *al.*, 2008), geographical range size and local abundance.
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52 406 Overall, reptiles are usually considered more resistant to global warming effects than
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54 407 amphibians because they have evolved a set of adaptations to water scarcity, such as eggs
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56 408 with calcareous shells (while amphibian eggs are enclosed by simple gelatinous membranes),
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58 409 and the excretion of metabolic wastes in the form of urea or uric acid, which is an adaptation
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60 410 to retain body-water (Gibbons *et al.*, 2000). Additionally, most reptiles are not dependent on

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3 411 water for reproduction. Although more specific climatic tolerances might be difficult to
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5 412 determine, they may be inferred by morphological traits or by the complete climatic envelope
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8 413 of species. Also, the climatic envelope of phylogenetic related species might provide some
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10 414 clues, if one considers niche conservatism (Hawkins *et al.*, 2007). For example, species
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12 415 belonging to clades that evolved under warm environments may be more tolerant to global
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15 416 warming.

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18 417 Species with restricted ranges are relatively more vulnerable to climate change because
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20 418 contractions of their small range will not be balanced elsewhere. From this point of view,
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22 419 species with very restricted distributions predicted to completely lose suitable habitat in the
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24
25 420 Iberian Peninsula such as *Iberolacerta aranica*, *I. aurelioi*, and *Rana pyrenaica* may be more
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27 421 impacted by climate change than more widespread Iberian species such as *Lissotriton boscai*
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29
30 422 or *Chalcides bedriagai*.

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32 423 Demographic parameters are also important factors in determining resistance to climate
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34 424 change (Keith *et al.*, 2008). Species with restricted ranges but with high local abundance may
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36 425 have more chances to adapt because genetic variation and potential response to selection
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38 426 pressures are positively correlated with population size. Thus, biological traits that regulate
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40 427 abundance, such as reproductive rates, age of female sexual maturity and life span length are
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42 428 also relevant. *Discoglossus galganoi* and *Podarcis bocagei* are species predicted to
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44 429 completely lose their range in the Iberian Peninsula but have high abundance and
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47 430 reproductive rate, and consequently will probably be less impacted by climate change than
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50 431 the others will.

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54 432 The adaptive capacity (or plasticity) of a species describes the intrinsic ability of a species to
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56 433 adapt to changing conditions. Species might be able to adjust their behaviour and phenology
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58 434 by switching periods of daily activity, aestivation and hibernation towards more favourable
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60 435 climatic conditions (Parmesan, 2007). Species might also be able to evolve traits that allow

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3 436 them to adapt to different climatic conditions (Harte *et al.*, 2004, Bradshaw *et al.*, 2006).
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5 437 Adaptation ability may be species-specific, however, the current knowledge is insufficient to
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8 438 determine which species are more able to adapt and further studies and monitoring are
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10 439 required to fully understand it.

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13 440 Species might also adapt to novel climate conditions by dispersing to other areas (Thuiller,
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15 441 2004, Massot *et al.*, 2008). Dispersion ability has been identified as one of the most decisive
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17 442 parameters in determining species resilience to climate change as species with greater
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19 443 dispersion ability may be able to track climate transitions. However this parameter is also one
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21 444 of the most difficult to determine. A growing body of literature proposes a vast collection of
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23 445 complex models to predict dispersion ability (reviewed by Thuiller *et al.*, 2008) but these
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25 446 require detailed data on an array of ecological processes that usually are unavailable for large
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27 447 numbers of species.

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32 448 A preliminary analysis of the model results and previous considerations indicate that species
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34 449 requiring more conservation attention under a climate warming perspective may be *Rana*
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36 450 *pyrenaica*, *Rana iberica* and *Calotriton asper* , within the amphibians, and *Iberolacerta*
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38 451 *aranica*, *Iberolacerta aurelioi*, *Iberolacerta bonnali* and *Iberolacerta monticola* within the
39
40 452 reptiles. However, this does not mean that these are the most vulnerable species to extinction,
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42 453 because this evaluation is only based on vulnerability to climate change, and does not account
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44 454 for other threats or the interaction of climate change with other threats (Brook *et al.*, 2008).
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46 455 Particularly, climate change is likely to induce further habitat changes and fragmentation (due
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48 456 to shifts in plant species distribution and an increase in fire incidence) and the spread of
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50 457 agents of infectious diseases such as the chytridiomycete fungus which is already across the
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52 458 Iberian Peninsula (Garner *et al.*, 2005). These factors are already considered the primary
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54 459 threats to amphibians and reptiles, along with pollution, invasive species, road kills and
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56 460 genetic depression.

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462 *From vulnerability to conservation actions*

463 Recommendations to address climate change impacts on biodiversity include a wide variety
464 of measures, with the most popular being monitoring species (with emphasis on the
465 physiological, behavioural and demographic response), restoring habitats and system
466 dynamics, expanding reserve networks, performing assisted dispersal Hoegh-Guldberg *et al.*
467 (2009), reducing other threats and increasing connectivity between suitable habitats (Heller *et*
468 *al.*, 2009, Lawler, 2009). Probably the most important questions for management are whether
469 species will be able to adapt to future climate conditions without the need to disperse or, if
470 not, if they will be able to disperse. Because these questions are difficult to answer with
471 current knowledge, novel management tools that promote flexible decision-making are
472 emerging, such as adaptative management (Kareiva *et al.*, 2008). Following this
473 methodology, we recommend that monitoring should be directed at the most vulnerable
474 species identified by our research. To infer species-specific conservation measures, the
475 monitoring parameters should include: a) physiological changes in thermal tolerances; b)
476 phenological adjustments, such as changes in aestivation and hibernation periods along the
477 year; c) behavioural thermoregulation changes, such as burrowing or adjustments in daily
478 activity periods; d) quantification of dispersal rates; e) changes in population parameters,
479 such as abundance, fertility and mortality f) incidence of infectious diseases and g) species
480 interactions.

481 If species are not able to disperse, then management measures will be needed in order to
482 assist local adaptation. Habitat restoration has been proposed as a proactive measure to
483 enhance amphibian resilience to climate change. In particular, a denser network of ponds and
484 water tanks has been recommended for amphibians (Blaustein *et al.*, 2001) in Mediterranean
485 areas. This measure, along with a careful control of river flow and water quality may increase

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3 486 the probability of amphibians to find suitable habitats during climate warming. Availability
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5 487 of freshwater habitats will be particularly important in the regions predicted to have high
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8 488 species loss, the northern Iberian Peninsula and main mountain systems, but also in extreme
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10 489 southern regions (Beja *et al.*, 2003).

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13 490 Assisted colonisation has been suggested, as a measure to assist climate change adaptation
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15 491 (Mueller *et al.*, 2008; Cheddadi *et al.*, 2009). This triggered intense debate (McLachlan *et al.*,
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18 492 2007) because translocation of species originated catastrophic impacts in many existing
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20 493 cases. However, assisted dispersal is particularly relevant for amphibians and reptiles due to
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22 494 their low dispersal ability, and therefore we cannot disregard this management possibility
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24
25 495 under an extreme probability of extinction scenario. However, we agree with (Hoegh-
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27 496 Guldberg *et al.*, 2008) in that assisted dispersal should only be considered for a given species
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29 497 if at least one of a set of assumptions is met, namely: a) the species should be in immediate
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31 498 risk of extinction; b) species should have low dispersal ability and c) the species range should
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33
34 499 be highly fragmented. Moreover, those authors suggest that translocations should only be
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36 500 undertaken within biogeographic regions, *i.e.*, regions that share similar species composition,
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38 501 and an assessment of translocation risks should be performed previously, including ecological
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40 502 and socio-economical risks. Translocation risk should subsequently be balanced against those
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42 503 of extinction and safeguarded by detailed scientific understanding.
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47 504 Protected areas have long been considered one of the most effective tools to conserve
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49 505 biodiversity (Rodrigues *et al.*, 2004), but their effectiveness in securing species under rapid
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51 506 climate change is uncertain (Araújo *et al.*, 2004). However they contribute to minimising
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53 507 threats such as, habitat destruction and fragmentation, road kills and pollution, which
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55 508 ultimately may assist to protect species threatened by climate warming. Therefore, it is
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57 509 important to evaluate if present protected areas would be effective in securing species given
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59 510 their predicted range shifts and whereas there is habitat connectivity between current and
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3 511 future species distributions. This could be achieved using reserve selection algorithms (*e.g.*
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5 512 Moilanen, 2009), which allow the identification the minimum set of areas necessary to
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8 513 represent all species at a given target. Ultimately, the ability of species to adapt to climate
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10 514 change within nature reserves will depend on the management actions undertaken in each of
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12 515 them. Reserve selection algorithms may also assist in identifying areas within nature reserves
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15 516 where the return of the management investment will be greater for a higher number of
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17 517 species.

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20 518 If species are able to disperse to new habitats, than management actions will be needed to
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22 519 facilitate dispersal, including the increase of habitat connectivity, in particular of freshwater
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25 520 habitats.

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28 521 Finally, biodiversity conservation can only be successful under climate change scenarios if
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30 522 socio-economical and environmental policies are integrated and if governments cooperate.
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32 523 Although climate change is a global issue, there is a tendency for actions to be taken by
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34 524 governments individually or by local administration, even with a common European
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36 525 environmental policy. It is recommended that the Portuguese and the Spanish governments
37
38 526 embark on joint efforts to conserve Iberian biodiversity, particularly Iberian endemics.
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Table 1 – Amphibian species list, conservation status under IUCN criteria (NE – not evaluated, LC – least concern, NT – near threatened, VU – vulnerable, EN – endangered), number of grid cells where each species is currently predicted to occur (current), number of grid cells where habitat is predicted to become unsuitable (negative values) or become suitable (positive values) in the future and overall tendency under storylines A2 and B2 and unlimited dispersal assumption. * indicates species strictly endemic to the Iberian Peninsula.

Species	IUCN	Current	2020	2050	2080	Tendency	2020	2050	2080	Tendency
<i>Alytes cisternasii</i> *	NT	2123	2460	1263	2114	Expansion/ Contraction	1496	760	1164	Expansion/ Contraction
<i>Alytes dickhilleni</i> *	VU	415	-415	-414	-415	Contraction	-415	-415	-415	Contraction
<i>Calotriton asper</i> **	NT	385	-200	-384	-385	Contraction	-173	-316	-385	Contraction
<i>Chioglossa lusitanica</i> *	VU	790	-727	-750	-788	Contraction	-790	-734	-774	Contraction
<i>Discoglossus galganoi</i> *	NT	2472	2286	2472	2472	Contraction	-2337	2428	2416	Contraction
<i>Discoglossus jeanneae</i> *	NT	1474	1991	3922	4684	Expansion	2805	2439	5052	Expansion
<i>Lissotriton boscai</i> *	LC	2371	3571	-40	1776	Expansion/ Contraction	3148	1177	553	Expansion
<i>Pelobates cultripipes</i>	NT	3087	3988	4232	3936	Expansion	3998	4097	3933	Expansion
<i>Pelodytes ibericus</i> *	LC	927	-2	487	-648	Contraction/ Expansion/Contraction	86	228	210	Expansion
<i>Pelophylax perezi</i>	LC	5607	-864	-47	1849	Contraction	-617	-752	-526	Contraction
<i>Pleurodeles waltl</i>	NT	2826	-689	1751	-284	Contraction	-974	1710	1	Contraction
<i>Rana iberica</i> *	VU	1324	-370	1115	1324	Contraction	-673	-946	1132	Contraction
<i>Rana pyrenaica</i> **	VU	89	-89	-89	-89	Contraction	-89	-89	-89	Contraction
<i>Triturus marmoratus</i>	LC	2080	2075	2080	2080	Contraction	-2080	2080	2080	Contraction
<i>Triturus pygmaeus</i> *	NT	1358	1277	1849	1585	Expansion	1649	1674	1849	Expansion

Table 2 – Reptile species list, conservation status under IUCN criteria (NE – not evaluated, LC – least concern, NT – near threatened, VU – vulnerable, EN – endangered), number of grid cells where each species is currently predicted to occur (current), number of grid cells where habitat is predicted to become unsuitable (negative values) or become suitable (positive values) in the future and overall tendency under storylines A2 and B2 and unlimited dispersal assumption. * indicates species strictly endemic to the Iberian Peninsula.** indicates species endemic to the Pyrenean Mountains.

Species	IUCN	Current	2020	2050	2080	Tendency	2020	2050	2080	Tendency
<i>Acanthodactylus erythrurus</i>	NT	2545	4004	4354	4627	Expansion	3753	4065	4341	Expansion
<i>Algyroides marchi</i> *	VU	204	-155	292	305	Contraction/ Expansion	49	257	-65	Expansion/ Contraction
<i>Blanus cinereus</i> *	LC	2778	1725	2152	2398	Contraction	1787	1620	2416	Expansion
<i>Chalcides bedriagai</i> *	NT	2344	2891	3553	3510	Expansion	2432	2679	4110	Expansion
<i>Chalcides striatus</i>	LC	2937	1108	-263	-249	Expansion/ Contraction	714	-702	741	Expansion
<i>Coronella girondica</i>	LC	2899	4606	2082	4572	Expansion	2484	2432	4689	Expansion
<i>Hemorrhois hippocrepis</i>	LC	2583	1313	2325	2326	Expansion	1275	1962	2720	Expansion
<i>Iberolacerta aranica</i> **	CR	23	-23	-23	-23	Contraction	-23	-23	-23	Contraction
<i>Iberolacerta aurelioi</i> *	EN	19	-19	-19	-19	Contraction	-19	-19	-19	Contraction
<i>Iberolacerta bonnali</i> **	VU	64	-64	-64	-64	Contraction	-64	-64	-64	Contraction
<i>Iberolacerta cyreni</i> *	EN	867	-427	-588	-750	Contraction	-426	-538	-742	Contraction
<i>Iberolacerta monticola</i> *	VU	524	-469	-524	-524	Contraction	-524	-524	-524	Contraction
<i>Lacerta schreiberi</i> *	NT	1560	778	-367	-875	Expansion/ Contraction	-95	-54	-401	Contraction
<i>Podarcis bocagei</i> *	LC	807	-761	-806	-807	Contraction	-807	-807	-806	Contraction
<i>Podarcis carbonelli</i> *	VU	519	212	-226	-499	Expansion/ Contraction	209	-193	-7	Expansion/ Contraction
<i>Podarcis hispanica</i>	LC	4522	2233	2367	2926	Expansion	2235	2294	3033	Expansion
<i>Psammmodromus algirus</i>	LC	4311	2643	1170	1220	Expansion/ Contraction	1842	1349	1470	Expansion
<i>Psammmodromus hispanicus</i>	LC	2882	1705	2403	2524	Expansion	1959	2416	3736	Expansion
<i>Rhinechis scalaris</i>	LC	2674	4742	4915	4927	Expansion	4832	4911	4922	Expansion
<i>Timon lepidus</i>	LC	4080	1325	1219	1950	Contraction	-1974	1310	-20	Contraction

<i>Vipera latastei</i>	VU	2688	3865	3873	3630	Expansion	3344	3890	3139	Expansion
<i>Vipera seoanei</i> *	EN	873	-867	-873	-873	Contraction	-873	-873	-873	Contraction

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1 **Table 3** – Species predicted to completely lose distribution range in the Iberian Peninsula until each of the
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 3 periods (2020, 2050 and 2080) according to storylines (A2, B2 or both) and under the unlimited dispersal
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 5 scenario. * indicates species strictly endemic to the Iberian Peninsula.** indicates species endemic to the
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 7 Pyrenean Mountains.
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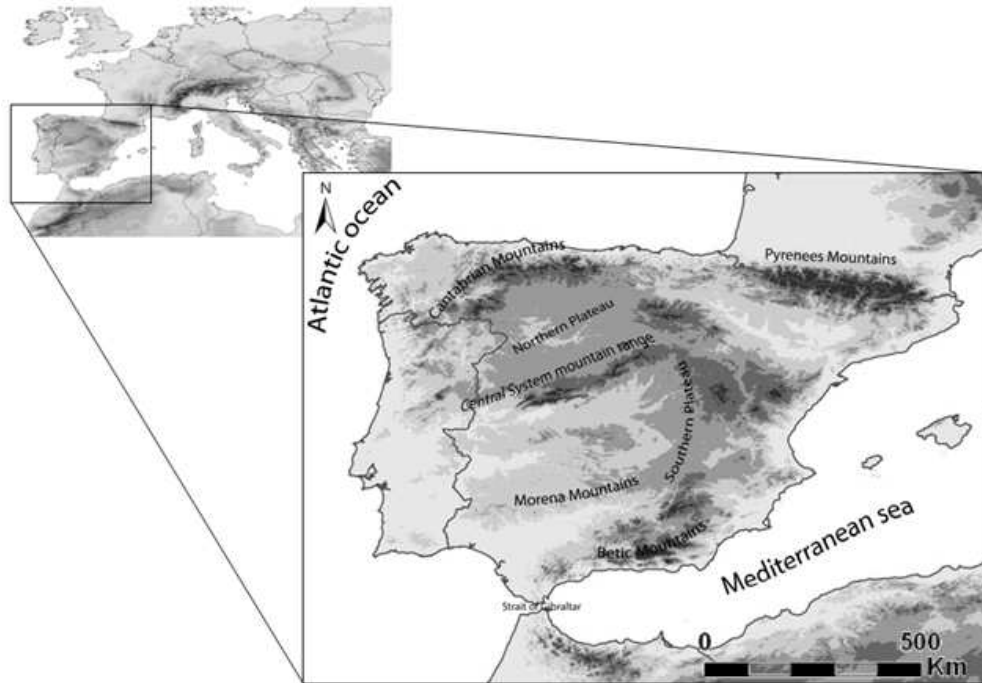
Species	2020	2050	2080
<i>Alytes dickhilleni</i> *	A2/B2	B2	A2/B2
<i>Calotriton asper</i> **	-	A2	A2/B2
<i>Chioglossa lusitanica</i> *	B2	-	-
<i>Discoglossus galganoi</i> **	-	-	A2
<i>Iberolacerta aranica</i> **	A2/B2	A2/B2	A2/B2
<i>Iberolacerta aurelioi</i> *	A2/B2	A2/B2	A2/B2
<i>Iberolacerta bonnali</i> **	A2/B2	A2/B2	A2/B2
<i>Iberolacerta monticola</i> *	B2	A2/B2	A2/B2
<i>Podarcis bocagei</i> *	B2	B2	A2
<i>Rana iberica</i> *	-	-	A2
<i>Rana pyrenaica</i> **	A2/B2	A2/B2	A2/B2
<i>Triturus marmoratus</i>	B2	A2/B2	A2/B2
<i>Vipera seoanei</i> *	B2	A2/B2	A2/B2

Appendix A.1 –Maximum (Max), Minimum (Min) and standard deviation (STDV), of the number of occurrences predicted for each amphibian species in each year and in each storyline, within the 9 modelling methods and the 3 global circulation models.

Species	2020						2050						2080					
	A2			B2			A2			B2			A2			B2		
	Max	Min	STDV	Max	Min	STDV	Max	Min	STDV	Max	Min	STDV	Max	Min	STDV	Max	Min	STDV
<i>Alytes cisternasii</i>	7293	71	2242.1	7535	34	2370.0	7207	2	2740.5	7023	8	2479.8	7602	0	2647.8	7602	0	2653.5
<i>Alytes dickhilleni</i>	5358	0	1406.3	5822	0	1795.8	5529	0	1792.7	5598	0	1695.5	7602	0	2315.4	7602	0	2305.5
<i>Calotriton asper</i>	7599	0	2858.6	7600	0	1755.6	4292	0	1090.9	7581	27	2156.2	7434	0	2258.4	7587	0	2203.3
<i>Chioglossa lusitanica</i>	1064	0	350.9	886	0	295.2	1584	0	391.5	7385	0	1393.2	3156	0	709.1	2428	0	524.7
<i>Discoglossus galganoi</i>	7420	0	2234.4	6310	0	1748.5	4614	0	1809.2	4777	0	1737.1	7602	0	2906.3	7602	0	2683.6
<i>Discoglossus jeanneae</i>	7602	228	2569.2	7602	374	2461.3	7602	776	2443.3	7602	749	2360.1	7602	197	3010.9	7602	710	2608.1
<i>Lissotriton boscai</i>	7595	1076	2196.3	7345	167	2069.3	7199	31	2082.1	7212	490	1917.1	7602	0	2607.7	7602	0	2444.6
<i>Pelobates cultripes</i>	7602	52	2273.2	7602	162	2235.3	7569	148	2406.4	7521	122	2220.9	7602	0	2709.4	7602	0	2592.4
<i>Pelodytes ibericus</i>	7387	13	2051.0	7584	268	2059.7	7516	509	2088.5	6857	22	1866.0	7519	0	2373.3	7328	0	2256.2
<i>Pelophylax perezi</i>	7601	372	2572.3	7602	347	2523.7	7602	315	2561.0	7602	311	2424.0	7602	0	2789.7	7602	0	2794.3
<i>Pleurodeles waltl</i>	7170	7	2255.1	7552	291	2124.8	7308	73	1997.5	7391	154	1912.2	7602	0	2568.5	7602	212	2544.5
<i>Rana iberica</i>	4186	7	1271.4	7511	0	1873.9	7413	0	1834.1	7503	0	2230.5	7515	0	2163.2	7544	0	2186.6
<i>Rana pyrenaica</i>	7487	0	2225.4	7389	0	1954.3	7466	0	2385.7	7590	0	2394.7	7548	0	2077.4	7490	0	2383.3
<i>Triturus marmoratus</i>	4589	0	1458.7	6450	0	1729.7	7313	0	1841.9	3889	0	1193.0	4473	0	1266.2	4179	0	1244.7
<i>Triturus pygmaeus</i>	7602	248	2386.1	7590	651	2141.6	7106	133	2218.2	7034	90	2155.6	7602	0	2720.7	7602	406	2336.6

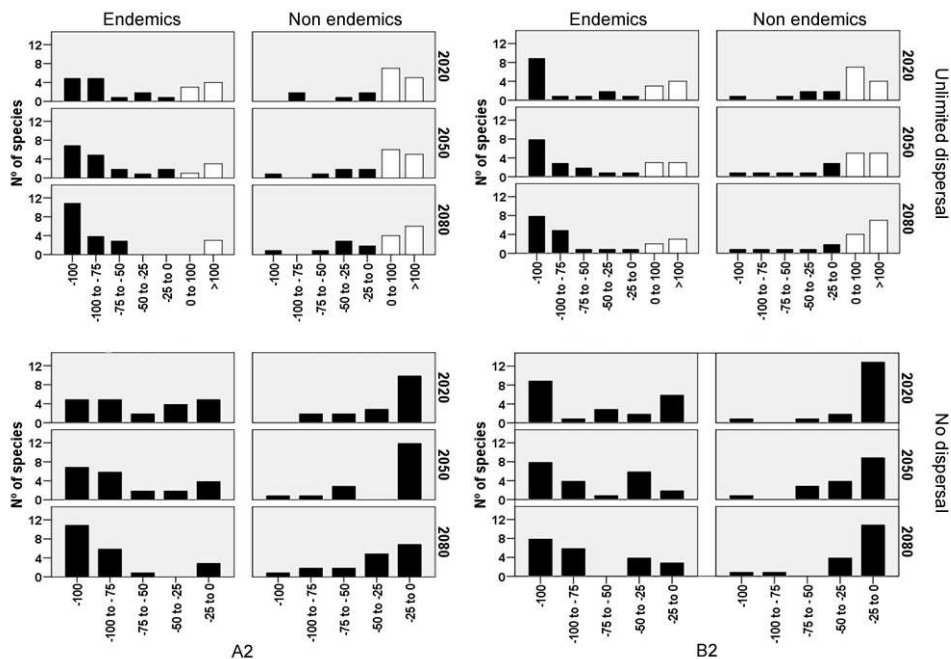
Appendix A.2 –Maximum (Max), minimum (Min), and standard deviation (STDV), of the number of occurrences predicted for each reptile species in each year and in each storyline, within the 9 modelling methods and the 3 global circulation models.

Species	2020						2050						2080					
	A2			B2			A2			B2			A2			B2		
	Max	Min	STDV	Max	Min	STDV	Max	Min	STDV	Max	Min	STDV	Max	Min	STDV	Max	Min	STDV
<i>Blanus cinereus</i>	7322	591	1676.3	7524	636	1693.2	7369	850	1707.5	6521	374	1691.0	7602	34	2593.4	7602	73	2157.2
<i>Chalcides bedriagai</i>	7598	53	2481.0	7148	268	2297.7	7409	299	2470.3	7376	111	2394.4	7602	20	3096.2	7602	63	2818.1
<i>Chalcides striatus</i>	7602	328	2238.7	7466	47	2164.6	7509	157	2316.2	7307	396	2121.2	7602	59	2565.4	7602	515	2502.4
<i>Coronella girondica</i>	7602	182	2662.8	7602	52	2788.2	7602	157	2599.1	7602	262	2676.9	7602	74	2992.2	7602	130	2815.2
<i>Hemorrhois hippocrepis</i>	6982	1380	1545.2	6359	902	1468.2	7281	1241	1835.1	7121	1208	1719.0	7602	0	2510.3	7602	0	2137.0
<i>Iberolacerta aranica</i>	463	0	122.1	2553	0	489.7	122	0	28.3	7493	0	1441.0	7600	0	1461.8	7592	0	1458.5
<i>Iberolacerta aurelioi</i>	7456	0	2368.1	7527	0	2390.1	7531	0	2401.9	7527	0	2377.6	7586	0	2414.6	7533	0	2400.6
<i>Iberolacerta bonnali</i>	7543	0	2406.0	7570	0	2413.6	7579	0	2420.1	7573	0	2402.6	7567	0	1459.5	7577	0	2418.1
<i>Iberolacerta cyreni</i>	7598	0	2327.3	7598	9	2324.0	7598	0	2320.5	7597	0	2343.6	7582	0	2331.2	7596	0	2393.4
<i>Iberolacerta monticola</i>	7510	0	2059.9	7446	0	1973.2	5825	0	1154.0	5002	0	982.8	6755	0	2171.6	6166	0	1612.7
<i>Lacerta schreiberi</i>	7378	361	2302.8	7235	0	2509.0	7325	0	2491.8	7291	58	2565.3	7602	0	2564.4	7313	0	2553.4
<i>Podarcis bocagei</i>	1609	0	527.1	1880	0	545.7	1786	0	561.8	1289	0	474.5	7602	0	1515.4	7602	0	1938.3
<i>Podarcis carbonelli</i>	7522	152	2816.1	7524	15	2654.5	7487	45	2465.4	6223	43	2142.9	7602	0	2742.7	7602	0	2703.4
<i>Podarcis hispanica</i>	7602	380	2543.7	7602	79	2739.4	7602	565	2756.7	7602	351	2626.6	7602	0	3080.0	7602	0	2922.5
<i>Psammotromus algirus</i>	7602	140	2737.2	7602	317	2747.0	7602	178	2833.4	7602	383	2740.9	7602	0	3224.3	7602	0	2889.7
<i>Psammotromus hispanicus</i>	7417	274	2760.3	7072	164	2697.7	7439	231	2974.2	7434	271	2867.7	7602	0	3164.2	7602	0	3026.3
<i>Rhinechis scalaris</i>	7602	372	2233.7	7602	82	2419.2	7602	1275	2299.2	7602	1538	2096.5	7602	0	2596.5	7602	0	2587.9
<i>Timon lepida</i>	7602	237	2466.0	7602	82	2709.5	7602	255	2772.4	7602	591	2616.2	7602	0	3121.7	7602	0	3022.9
<i>Vipera latastei</i>	7594	63	2148.9	6928	71	2270.8	7222	198	2178.5	7244	556	1811.9	7570	0	2997.2	7232	0	2838.1
<i>Vipera seoanei</i>	3144	0	643.7	949	0	265.2	3314	0	656.8	967	0	291.6	4931	0	967.9	4811	0	940.0



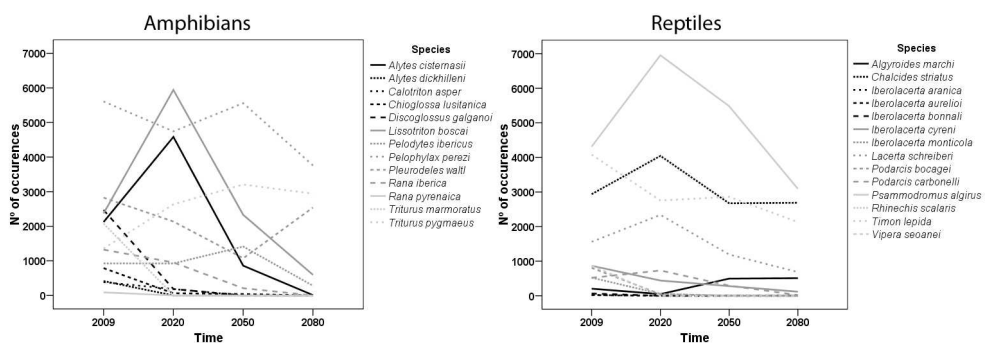
Location and map of the Iberian Peninsula depicting altitude and major geographic features. Altitude is represented in a range of grey colours where darker areas represent higher altitude.
168x123mm (96 x 96 DPI)

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Number of species predicted to gain or lose suitable habitat under different dispersion assumptions (unlimited dispersal and no dispersal) and storylines (A2 and B2), categorised by the percentage of range contraction or expansion relatively to present (x axis). Endemics and non endemics species are represented separately, with endemics representing species strictly endemic to the Iberian Peninsula and species endemic to the Pyrenean Mountains. Black columns represent species predicted to lose suitable habitat while white columns represent species predicted to gain suitable habitat.

275x190mm (96 x 96 DPI)



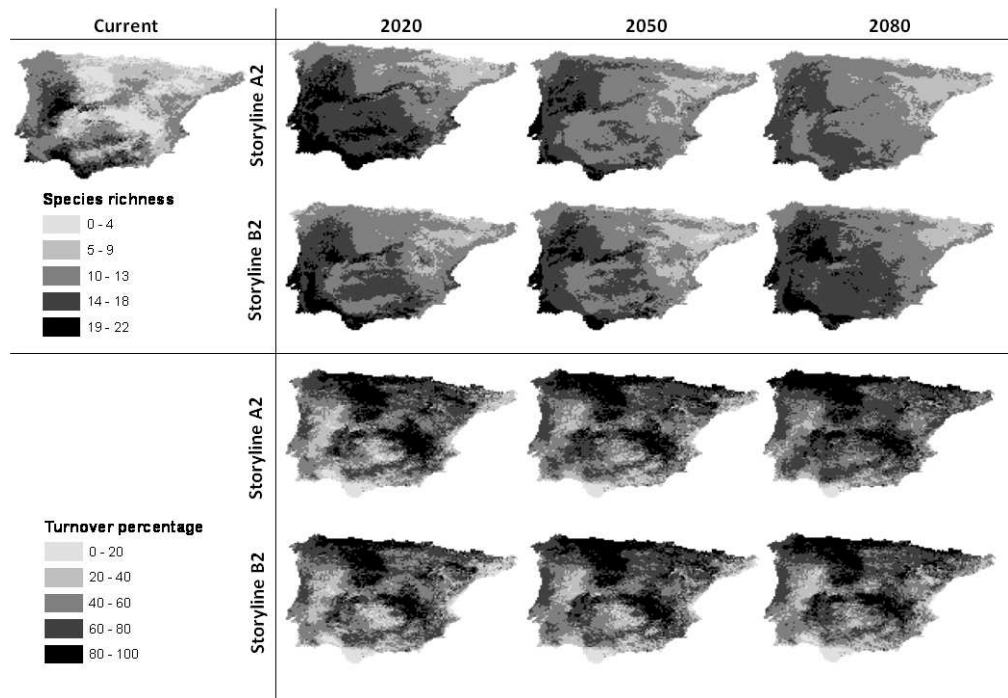
Variation in the predicted number of occurrences through time for species predicted to lose suitable habitat according to the unlimited dispersion scenario and storyline A2.

132x47mm (300 x 300 DPI)

Review Only

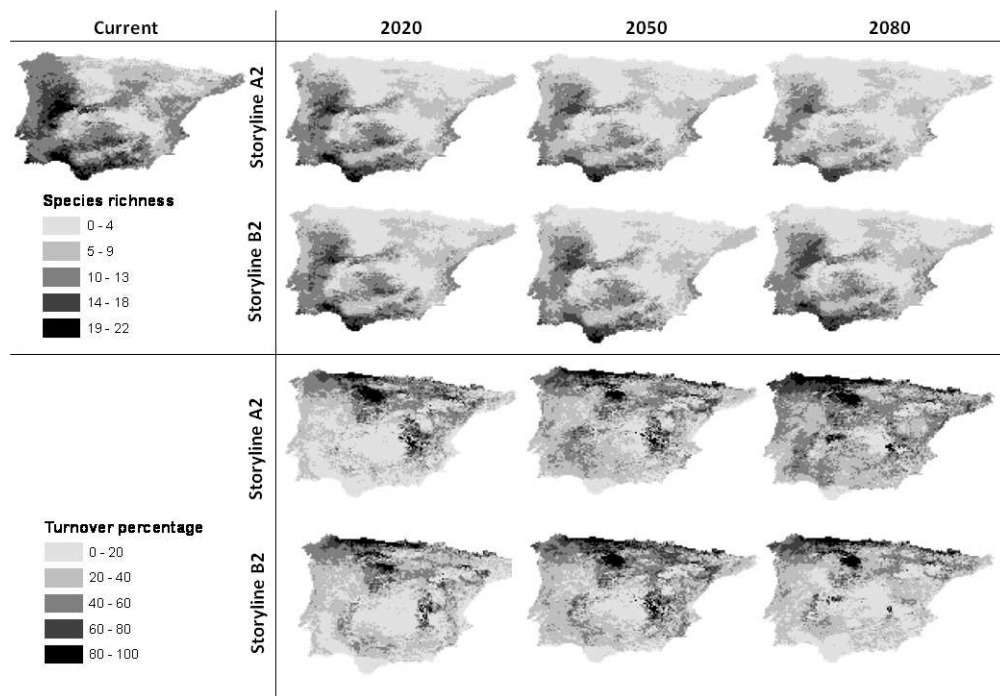
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Spatial distribution of predicted current and future (2020, 2050 and 2080) species richness and turnover percentage according to storylines A2 and B2 and under the unlimited dispersion scenario. 275x190mm (96 x 96 DPI)

View Only

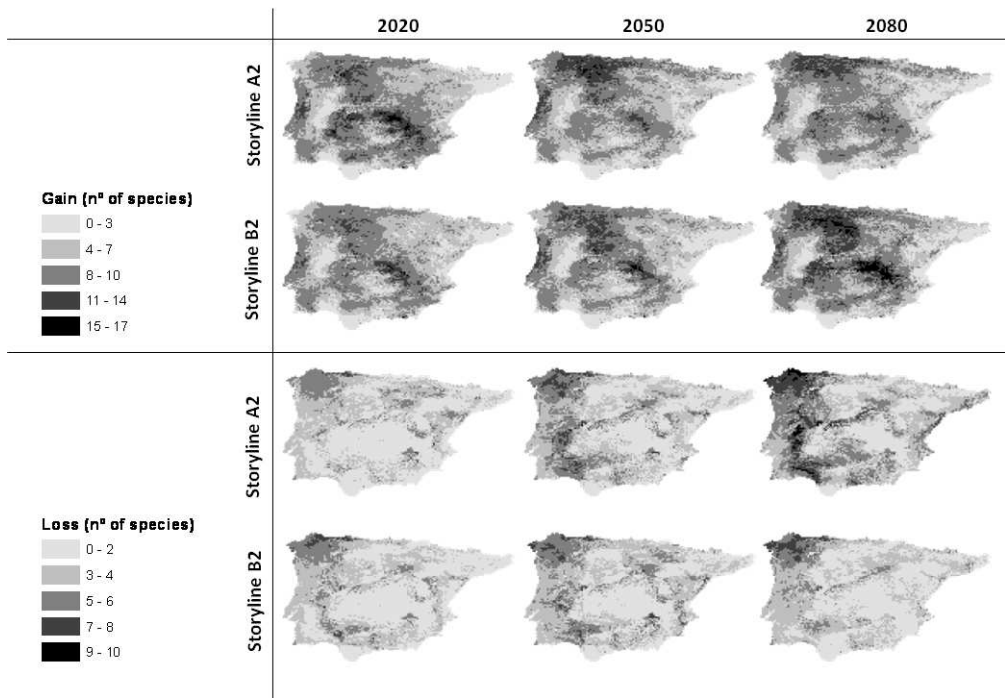


Spatial distribution of predicted current and future (2020, 2050 and 2080) species richness and turnover percentage according to storylines A2 and B2 and under the no dispersion scenario. 275x190mm (96 x 96 DPI)

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Spatial distribution of predicted gain (under the unlimited dispersion scenario) and loss (in both dispersion scenarios) of number of species in the future (2020, 2050 and 2080) according to storylines A2 and B2 and under the unlimited dispersion scenario.
275x190mm (96 x 96 DPI)