Effects of climate change on the distribution of threatened invertebrates in a Mediterranean hotspot

Running title: Iberian invertebrates and climate change

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Abstract

1. The effects of climate change may constitute a major threat factor for endemic and threatened species of invertebrates. A particularly dramatic case can be found in the Iberian Peninsula, because of its high rate of species diversity and endemism. We aim to evaluate the effects of climate change on the distribution of 36 endangered and endemic species of invertebrates within the Iberian Peninsula using species distribution models.

2. We used an ensemble species distribution modeling framework to estimate the species potential distributions under current and future (2050 and 2070) climatic conditions for two different areas: the whole Iberian Peninsula and the current species ranges. We assessed species vulnerability to climate change by calculating three complementary indexes: Change in Suitable Area, Persistence in Suitable Area and Turnover in Suitable Area.

3. Annual Mean Precipitation was the variable that contributed most to the climatic models. We categorized 25 species as “losers” because they will experience a reduction in their total suitable area under future climatic conditions, six species were categorized as “winners” and six showed contradictory results.

4. Climate change will have several effects on species by changing their suitable distributions and may affect their persistence. Species with narrow distributions associated to mountain ranges will experience the worst future projected conditions, while arid adapted species are expected to expand their distributions. Factors assessing the vulnerability of endemic and endangered species can be taken into account to develop strategies that mitigate the negative effects of climate change.

Keywords: Species Distribution Models, endemics, Iberian Peninsula, global warming, vulnerability, niche shift

Introduction

Climate change (CC) is expected to become one the greatest drivers of global biodiversity loss and may be the largest anthropogenic disturbance ever placed in natural systems during the 21st century (Thomas *et al.*, 2004; Heller & Zavaleta, 2008; Urban, 2015; Jourdan *et al.*, 2018). Global average temperatures are predicted to increase in the future while precipitation patterns have changed in the last 100 years and are expected to keep changing in the future (IPCC, 2014). Among other factors, to assess the vulnerability to CC of species, it is necessary to study the rate in which their distributional ranges are affected by said phenomenon. The effects of CC may constitute a major factor of threat for endemic and threatened species (Thuiller *et al.*, 2005; Urbani *et al.*, 2017; Prather *et al.*, 2013), acting either alone or synergistically with other stressors, such as land transformation and pollution (Parmesan, 2006; Preston, 2008). Effects of CC are spatially heterogeneous and site dependent.

For instance, in the Iberian Peninsula, CC is projected to worsen conditions with extreme temperature events (Viceto *et al*., 2019) and change in precipitation patterns that will amplify desertification in the region (Pereira *et al*., 2020). The case of the Iberian Peninsula, within the Mediterranean biodiversity hotspot, can be particularly dramatic in the context of CC. The favorable biogeographical position, variety of climates and landscapes, and the extensive coastline grants to the Iberian Peninsula extraordinary natural conditions. In fact, the Iberian Peninsula is regarded as one of the richest European regions in terms of species diversity, endemism and ecosystem diversity and as well as a point of reference on the issue of conservation (Médail & Quézel 1997; Domínguez-Lozano *et al.*, 1996; Reyjol *et al.*, 2007). About 98% of the total Iberian fauna are invertebrates (Ramos *et al.*, 2001). Invertebrates are likely to be vulnerable to climate change because their physiological functions are strongly influenced by external temperature (Deustch *et al.*, 2008). Climate has a direct influence on the development, reproduction and survival of invertebrate species, and especially insects (Bale *et al.*, 2002). Warming potentially may have an effect on life-cycle, changes in phenological patterns, changes in habitat selection and expansion and contraction of geographic ranges (Menendez, 2007). Even so, there is a lack of knowledge about their environmental adaptations towards changes in climate (Cardoso *et al.*, 2011).

Obtaining reliable information regarding the distribution of invertebrate species will help to develop effective conservation measures to face climate change (Parmesan, 2011; Pereira *et al.*, 2010). The large projected impacts of climate change on biodiversity means that ecologists must rise to the challenge of providing guidance for the development of conservation strategies (Araujo *et al.*, 2011). A primary method for predicting species response to climate warming is the use of species distribution models (SDMs). Since species can adapt to novel climatic conditions by shifting their ranges into newly favorable areas (Parmesan, 2006), these projections may show shifts in species ranges, either expansion, contraction or direction. Model predictions of where, when and how future risks may affect species or ecosystems could assist in identifying the most appropriate conservation measures (Bellard *et al.*, 2012).

This study aims to evaluate the effects of climate change on the distribution of endangered and endemic species of invertebrates in the setting of the Iberian Peninsula using SDMs. Climate change will alter the suitability of habitats for a species' establishment, growth, and reproduction, causing species distributions to change and, thus, species would need to disperse to new suitable areas. Consequently, the vulnerability of species to global warming will depend on the availability of suitable habitat in the future, but also on their capacity to reach these suitable future environments (i.e. their dispersal ability; Arribas *et al.*, 2012). Therefore, the main objective of this study is to assess the vulnerability of endangered endemic invertebrates by measuring different parameters of range change to account for the degree to which certain species depend on dispersal capacity to shift their distributions under global warming.

Methods

Study area and data

The study area comprises the Iberian Peninsula. This territory is characterized by a wide variety of biomes, relief, climates and soil types (Hernández-Manrique *et al.*, 2012). Despite being located within the same temperate zone, changes in topography of the peninsula also provide a great diversity of climates (e.g. Mediterranean, oceanic, alpine) and variety of landscapes ranging from arid to more mesic environments. Paleogeographic and paleoclimatic events from the past have produced several isolations providing refugees during glacial and interglacial periods that contribute to the increase of the biodiversity in the study area (Hernández-Manrique *et al.*, 2012).

The species distribution data used were extracted from the Spanish Inventory of Terrestrial Species (available at www.miteco.gob.es), which compiles records of invertebrate distribution in Spain on 10 × 10 km UTM grid cells. We focused on those endangered invertebrate species (either Vulnerable, Endangered and Critically Endangered *sensu* the Spanish Atlas of Threatened Invertebrates; Verdú & Galante, 2009; Verdú *et al.*, 2011), endemic to the Iberian Peninsula and with at least 10 occurrences (10 x 10 UTM cells) in the dataset. Therefore, we filtered for 37 species of different threatened invertebrates endemic (two of them are endemic to Pyrenees and also have some occurrences in France) to Iberian Peninsula that met such criteria (Table 1). This final dataset included species belonging to Insecta (27), Gastropoda (6), Arachnida (3) and Mollusca (1). As species occurrences were obtained in UTM coordinate system and bioclimatic variables were obtained in WGS-1984 coordinate system (see below), a previous transformation of biological data to WGS coordinate system was required.

Nineteen bioclimatic variables were obtained from WORLDCLIM 1.4 database (http://www.worldclim.org/; Hijmans *et al.*, 2005) at a spatial resolution of 5 arc-minutes (approximately 10 km cell size) for present and future (years 2050 and 2070) climatic conditions. For the future, we considered two Representative Concentration Pathways (RCP), 4.5 and 8.5, representing moderate and high future warming scenarios, respectively, and 17 general circulation models (GCMs) available for these RCP in WORLDCLIM database.

Species distribution modeling

We ran SDMs to infer current and future potential distributions of each of the 37 invertebrate taxa within the Iberian Peninsula through an ensemble species distribution modelling approach (Araújo & New, 2007) using the 'Biomod2' R package (Thuiller *et al.*, 2021). Four techniques were used in the ensemble modeling: generalized linear models (GLM), generalized additive models (GAM), maximum entropy (Maxent) and random forest (RF). To avoid multicollinearity problems, only a single variable from sets of highly correlated variables (Pearson $r > 0.8$) was used in the modeling (see e.g. Abellán *et al.*, 2012), leaving a final set of eight climatic predictor variables: Annual Mean Temperature (BIO 1), Isothermality (BIO 3), Max Temperature of Warmest Month (BIO 5), Temperature Annual Range (BIO 7), Mean Temperature of Wettest Quarter (BIO 8), Mean Temperature of Driest Quarter (BIO 9), Annual Precipitation (BIO 12) and Precipitation Seasonality (Coefficient of Variation; BIO 15). For each species, the training area of the model was defined as the minimum convex polygon encompassing all the occurrence records buffered by 0.5 degrees, representing current accessible areas to the species via its movement or dispersal capabilities (Barve *et al.*, 2011). Pseudo-absence points were set up as 10,000 for all species and randomly drawn from the training area of each species. Presences and pseudo-absences were weighted as such to ensure neutral (0.5) prevalence. Models were calibrated and evaluated using two cross-validation approaches, depending on the number of occurrences of each species. For species with 20 or more occurrences, the available data was randomly split into training (80%) and test (20%) sets; we repeated this process ten times in each modelling run. For species with less than 20 occurrence records, we used a Jackknife (or ‘leave-one-out’) procedure (Pearson et al. 2007), so that each occurrence was excluded once from the training data set and the model built using the remaining n–1 occurrences. Thus, for a species with n presences, n independent models were built, each one evaluated using the single occurrence removed from the training set. In both approaches, individual models were evaluated using the area under the receiver operating characteristic curve (AUC) and the true skill statistic (TSS).

For each species, we build an ensemble model based on the four modelling techniques, each weighted based on the cross-validated TSS values. Predictive accuracy of ensemble models was assessed based on AUC, TSS, sensitivity (proportion of true positives correctly identified), specificity (proportion of true negatives correctly identified), and the Boyce Index. Variable importance was assessed in ‘biomod2’ as 1 minus the Pearson's correlation between the predictions of the full model and the predictions of the model where the target variable was randomized (Thuiller *et al.*, 2021). Final ensemble models were projected onto both present and future climate conditions in the Iberian Peninsula to obtain the current potential distribution of each species and under climate change. Finally, we converted the continuous suitability predictions into binary maps of presence/absence using *maximum training sensitivity plus specificity* threshold, as it performs well in comparison with other thresholds (Liu *et al.*, 2005).

Assessing spatial changes

To assess vulnerability of species to climate change we calculated three indexes providing information on the changes in availability of climatically suitable habitat in the future relative to the present, but also on the degree to which species will depend on dispersal to reach future suitable environments (see e.g. Arribas *et al.*, 2012): Change in Suitable Area (CSA), Persistence of Suitable Area (PSA) and Turnover in Suitable Area (TSA). CSA indicates the gain or loss in percentage of suitable area in the future in relation to the current suitable area (equation 1; Fig. 1D). PSA represents the percentage of current suitable area that will remain suitable for the species in the future (equation 2; Fig. 1D). Finally, TSA represents the percentage of future suitable area what represents turnover (i.e., the percentage of new suitable grid cells as a fraction of the total suitable area in the future) (equation 3; Fig. 1D).

$$(1) \qquad CSA = \frac{F*100}{P} - 100$$

$$(2) \qquad PSA = \frac{S*100}{P}$$

$$(3) \qquad TSA = \frac{(F-S)*100}{F}$$

where P is the climatically suitable area in the present, F is the suitable area in the future, and S is the area climatically suitable in both the present and the future. CSA provides information on the increase or reduction in the amount of suitable habitat for species in the future relative to current habitat availability. Species gaining suitable climate conditions are termed “winners” and the ones that lose suitable climate conditions are termed “losers” (Araujo *et al.*, 2011). Furthermore, both PSA and TSA represent two complementary ways of evaluating the degree to which species depend on dispersal to shift their distributions under global warming. For instance, species with low values of PSA and high values of TSA will only survive under future conditions if they are able to reach future suitable areas, so their survival will depend on intrinsic species traits such as dispersal ability, and habitat connectivity. On the other hand, species with very low values of both PSA and TSA are likely to be most vulnerable to climate change, as they will not able to neither persist in their current populations nor shift their ranges.

To account for uncertainties associated with dispersal in the assessment of spatial changes, we considered two different scenarios, representing two extremes in species' dispersal capabilities. In the first scenario, species were assumed to be able to reach all the climatically suitable areas in the study area (Iberian Peninsula). In the second scenario, species were assumed to be able to reach only suitable habitat within the currently accessible area or current geographical range (i.e. the training area of the models as defined above). While both approaches overly simplify accessibility, they are useful to represent the uncertainty associated with the effects of climate change on habitat availability. RStudio 4.0.3 was used to perform the climatic models based on the R package *dismo* (Hijmans et al., 2017).

Results

Overall, SDMs performed well for most of the species (see Supporting Information Table S1). Ensemble models had an average test AUC of 0.952 (range = 0.879-0.997), and an average TSS of 0,823 (range = 0,587 - 0,981). Boyce index values were always positive with the only exception of *Unio tumidiformis*, for which a value of -0.423 was found. Annual Mean Precipitation (BIO 12) was the variable that contributed most often to the climatic models from the species list (Table S1), followed by the Annual mean range (BIO 7) and the Max Temperature of Warmest Month (BIO 5).

Species showed differential responses to climate change projections (Fig. 1; all maps in Supporting Information Appendix S1). In terms of Change in Suitable Area (CSA), 25 of the 36 species were categorized as “losers” because they are likely to experience a reduction in the total suitable area in the future scenarios (Fig. 1; Table 2; Supporting Information Table S2). Overall, the scenario for 2070 and RCP 8.5 predicted the most dramatic reduction in suitable habitat for such species, but no significant differences were found between scenarios for any index. Many species associated to mountain ranges suffered the most drastic reduction to their distributions, such as *Baetica ustulata*, which showed a reduction of 78.57% of its potential area within Iberia and 46.82% within its current range (Fig. 2). *Dolichopa bolivari* or *Norelona pyrenaica* were the mountain species that suffered the most habitat loss, as 100% of their current suitable area was reduced under both dispersal scenarios.

Six species were classified as “winners”, as they are likely to experience an increase in their potential suitable area under future conditions (Fig. 1, Table 2, Supporting Information Table S2), and for five of them, the increase in suitable habitat will be greater in 2070 and RCP 8.5 scenario, being *Apteromantis aptera* the one that will experience the maximum area gain with a 932% increase in its current range (Fig. 2). Furthermore, five species (*Carabus galicianus*, *Carabus ghilliani*, *Dericorys carthagonovae*, *Paratriodonta alicantina*, *Zygaena ignifera*) showed contradictory results between the different climatic scenarios and years (Table 2).

Winner species expected to maintain most of their present suitable area (under both dispersal scenarios) in the future, as they showed high PSA values (Table 2; Fig. 1). Some loser species in terms of CSA also showed lower values of PSA and, more specifically, five of the species are expected to lose in the future all their present suitable area (Table 2). This case is especially dramatic for species with a narrow distribution range, such as

D. bolivari or *N. pyrenaica*, whose CSA and PSA values showed the maximum reduction in suitable area in all climatic and dispersal scenarios (Table 2 and Supporting Information Table S2). Finally, TSA values revealed no new suitable areas in the future for 20 listed species for the most dramatic scenario (8.5 at 2070), which correspond to the species categorized as "losers" according to the other indexes (Table 2). Furthermore, many of the species (e.g. *Canariola emarginata*, , *Macrothele calpeiana*, *Omocestus femoralis*, *Thorestes valencianus*) that are expected to lose their current suitable area will experience a northwards shift in suitable habitat in the future (Fig. 2). On the other hand, species restricted to southeastern Iberia and associated with arid and semi-arid environments, such as *Derycoris carthagonovae*, *Melanopsis lorcana*and Cephalota deserticoloides (Fig. 2), will experience a great increase in the suitable area under future climatic conditions.

Discussion

The use of SDMs provides a first overview regarding the impact of climate change on species ranges (Pearson & Dawson, 2003). The use bioclimatic models can lead to an overlooked prediction of the species distributions since other non-climatic variables are not taken into account (Sinclair *et a*l., 2010). Besides climatic stressors, species distributions are also constrained by interactions with other organisms (e.g. competition, predation), trophic specialization or the degree of human impact which are not taken into account when developing current SDMs. However, at a larger scale, climatic influences are shown to be dominant over biotic interactions (Pearson & Dawson, 2003). Furthermore, climatic models also involve a certain degree of uncertainty when projecting to the future for technical or parameterization reasons (Goberville *et al*., 2015).

Despite those limitations, SDMs have promoted ecological theory and biodiversity conservation providing concise warnings regarding change in niche space change and interactions or movement across a fragmented environment (Dawson *et al*., 2011; Summers *et al*., 2012). The factors behind the vulnerability of endangered and endemic species to global warming can be taken into account to develop strategies that mitigate the negative effects of climate change, especially when working with endemic species that normally present few populations and narrow tolerance to changes (Urbani *et al*., 2017). Here we provided three different measurements for assessing distribution changes under climate change that, when used in combination, allow us to understand how endemic and endangered invertebrates from the Iberian Peninsula may change their distributional ranges and how their survival may depend on the ability to colonize new suitable areas in the future with respect to current scenarios.

Here we used two different dispersal scenarios to assess potential distribution changes from current to future conditions. Assuming that species are able to reach all the climatically suitable areas within the Iberian Peninsula may involve a higher degree of uncertainty than projections within their currently accessible area, as the former did not account for dispersal limitations within the study area, which might be unrealistic (Allouche *et al*., 2008). Empirical evidence indicates that current distribution patterns of the studied species are constrained by dispersal limitations, as they are endemic to Iberia (some species also occurring within the French Pyrenees), and are often restricted to narrow historical distributions (e.g. *Omocestus femoralis*, *Baetica ustulata*, *Berberomeloe insignis*). Hence, we would expect that the dispersal ability of many of the species will be also limited in the future (Rabitsch *et al*., 2016). Thus, future projections and vulnerability indices are likely to be more reliable within their current range, as short distance dispersal is more likely to happen.

Our study found different responses of threatened Iberian invertebrates to climate change. Overall, our results point to a loss of climatically suitable area for most of the species under future conditions, coupled with low levels of habitat persistence. These species, such as *Baetica ustulata, Canariola emarginata* or *Monsterratina martonelli,* can be considered as “losers” because of their drastic losses in their total habitat suitability and range contraction in their current range both in 2050 and 2070. Even in the best case scenario there are some species that are likely to lose 100% of their suitable habitat (e.g. *Norelona pyrenaica* and *Dolichopoda bolivari*). According the Spanish Atlas of Threatened Invertebrates (Verdú & Galante, 2009; Verdú et al., 2011), these “loser” species are currently considered as “vulnerable” under criterion B2 (area of occupancy <2,000 km^2). However, eight of these species (i.e. *Carabus pyrenaeus*, *Dolichopoda bolivari*, *Iberodorcadion ferdinandi, Hadjina wichti* and *Zabrus pinguis*) would be classified as “Endangered” under that criterion (area of occupancy <500 km^2) based on future predictions for both area estimations.

Many of these “loser” species inhabit mountain ecosystems, often with very narrow ranges restricted to a single mountain system within Iberia (e.g. *Baetica ustulata, Norelona pyrenaica*, *Carabus ghilianii* and *Carabus pyrenaicus*). They are more likely to have dispersal limitations, and are adapted to cold conditions because of their altitudinal ranges (Pallarés *et al*., 2019). Because mountainous environments combine a steep climatic gradient with a decline of available area with altitude, and experience some of the fastest rates of warming, these mountain species are particularly vulnerable to climate change (Elsen & Tingley, 2015). Those species that suffer high range contraction and present important dispersal limitations will also be affected by the lack of population connectivity between protected areas (Opermanis *et al*., 2012). Similarly, it is important to note that other anthropogenic changes than global warming, such as land-use changes, habitat degradation and fragmentation or the introduction of alien species may be important factors that drive reduction in the projected species distributions.

We would also expect that species related to water in any one stage of their lifecycle will become losers (e.g. *Melanopsis cariosa, Pseudamnicola gasulli*) in the future because of shifts in precipitation patterns due to climate change (Summer *et al*., 2003). However, *Melanopsis lorcana* showed an increase in their suitable area in the future. Furthermore, *U. tumidiformis* (a species of bivalve), had high unpredictability of the species. Therefore, the reliability of SDMs to water related species will need further research.

With an expected increase of 2°C in mean annual temperature in the next 100 years, many distributions are expected to suffer a northward shift of approximately 200 km (Wittman *et al*., 2001). Our models predict that many Iberian species will experience a change in suitable habitat in future scenarios involving northwards range shifts (e.g. *Omocestus femoralis* or *Sparedrus lencinae*). Although potential distributions may remain in the future, the accessible areas where the species are currently occurring would be drastically reduced (Pallarés *et al*., 2019). This mismatch between present and future conditions will likely depend on the dispersal ability of each species, but also on the landscape structure, presence of natural barriers and habitat fragmentation. Highly dispersive species will be able to fill the potential future space, whilst poor dispersers will occupy only those current areas that remain suitable under future climates (Pearson & Dawson, 2003). There are some cases in which this mismatch involves long distances from southern to northern latitudes of hundreds of kilometers, a distance which seems unlikely to be reached by non-flying macroinvertebrates. Ideally, a combination of the distances that organisms can disperse to, modes, frequency of dispersal, and how this relates to population characteristics would be recommended for future climatic studies (Sinclair et al., 2010).

Groups of species likely to experience a general increase in their climatically suitable area (in CSA, PSA and TSA) among their territory were considered as “winners” because they have better chances to adapt to climate change in their territory. Climate change is expected to produce changes in the precipitation patterns in areas surrounding the Mediterranean Sea likely resulting in an increase of droughts and aridity (Summer *et al.*, 2003). Arid-adapted species currently restricted to southern Iberia (e.g. *Cephalota Deserticoloides, Ochthebius glaber* and *Dericorys carthagonovae*) will likely be benefited by climate change by expanding their climatically suitable area according to our predictions. However, it should be noted that these species are associated to specific lithological conditions, notably calcareous and evaporitic outcrops (e.g. *Cephalota deserticoloides* and *Dericorys carthagonovae*) or hypersaline streams (*Ochtebius glaber*). Hence, for such halophile species which require specific habitats such as arid salt steppes, geological substrate is likely to be an important range constraint (Abellán et al., 2012). Because our models did not consider lithology or other non-climatic factors (e.g. biotic interactions such as dependence on host plants), the potential suitable habitat for both present and future conditions for these "winners" is likely overestimated.

SDMs have been very useful in conservation plans to map species distributions, but also to search for undetected new populations of modeled species or find suitable sites for reintroduction of threatened species (Sinclair *et al.*, 2010). SMDs may be combined with other useful tools, such as the R package *prioritizr* (Hanson et al., 2021), which allow to apply directly outputs from SDMs to determine specific optimal areas where conservation efforts should be focused.

Future conservation efforts should take into account that the distribution of biodiversity will likely be dramatically altered by climate change and an increase in risk of extinction and habitat reduction are one of the possible outcomes (Araujo *et al.*, 2011). Arribas *et al.* (2012) developed a framework to guide insect conservation efforts based on the species' persistence and the ability to shift ranges under changes in climatic. Efforts for "winner" species that are likely to maintain their present suitable area in the future should be concentrated in protecting the current areas. However, for “loser” species with a change in their suitable areas there will also need to be a reinforcement in the connectivity between present and future conditions to enhance their dispersal (Heller & Zavaleta, 2009). If future suitable areas for “loser” species occur at long distances, dispersal may not be feasible. Therefore, current population biomonitoring and habitat adaptation to mitigate climate change would be recommended.

Climate change will have several effects on species by changing their suitable distributions and affecting their persistence. SDMs allow us to have a first overview of the impact of climate change in several species of endemic and endangered invertebrates in Iberian Peninsula by projecting future suitable areas to 2050 and 2070. With an expected increase of temperatures and change in precipitation patterns by climate change, arid environments are expected to increase in the Iberian Peninsula. Species adapted to arid environments will improve their suitable area in the future, whilst others will suffer from a displacement of their suitable area or even a drastic reduction of their potential distribution.

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Table 1. Selection of the Iberian endemic species categorized as Vulnerable or Endangered according to the Spanish atlas of threatened invertebrates with at least 10 occurrences.

Species	Family	Order	Class	Threat category	N. of occurrences
Apteromantis aptera	*Mantidae*	*Dictyoptera*	*Insecta*	Vulnerable	35
Artimelia latreillei	*Arctiidae*	*Lepidoptera*	*Insecta*	Vulnerable	109
Baetica ustulata	*Tettigoniidae*	*Orthoptera*	*Insecta*	Vulnerable	13
Berberomeloe insignis	*Meloidae*	*Coleoptera*	*Insecta*	Vulnerable	29
Canariola emarginata	*Tettigoniidae*	*Orthoptera*	*Insecta*	Vulnerable	12
Carabus galicianus	*Carabidae*	*Coleoptera*	*Insecta*	Vulnerable	59
Carabus ghilianii	*Carabidae*	*Coleoptera*	*Insecta*	Vulnerable	18
Carabus pyrenaeus	*Carabidae*	*Coleoptera*	*Insecta*	Vulnerable	18
Cephalota deserticoloides	*Carabidae*	*Coleoptera*	*Insecta*	Vulnerable	10
Ceratophyus martinezi	*Geotrupidae*	*Coleoptera*	*Insecta*	Vulnerable	15
Coscinia romeii	*Arctiidae*	*Lepidoptera*	*Insecta*	Vulnerable	17
Dericorys carthagonovae	*Acrididae*	*Orthoptera*	*Insecta*	Vulnerable	25
Dolichopoda bolivari	*Rhaphidophoridae*	*Orthoptera*	*Insecta*	Vulnerable	17
Formica dusmeti	*Formicidae*	*Hymenoptera*	*Insecta*	Vulnerable	61
Hadjina wichti	*Noctuidae*	*Lepidoptera*	*Insecta*	Vulnerable	11
Iberodorcadion ferdinandi	*Cerambycidae*	*Coleoptera*	*Insecta*	Vulnerable	10
Leptopterna pilosa	*Miridae*	*Hemiptera*	*Insecta*	Vulnerable	37
Macrothele calpeiana	*Hexatheliidae*	*Araneae*	*Arachnida*	Vulnerable	124
Melanopsis cariosa	*Melanopsidae*	*Neotaenioglossa*	*Gastropoda*	Vulnerable	23
Melanopsis lorcana	*Melanopsidae*	*Neotaenioglossa*	*Gastropoda*	Vulnerable	26
Montserratina martorelli	*Hygromiidae*	*Pulmonata*	*Gastropoda*	Vulnerable	18
Norelona pyrenaica	*Xanthonychidae*	*Pulmonata*	*Gastropoda*	Vulnerable	10
Mylabris uhagonii	*Meloidae*	*Coleoptera*	*Insecta*	Endangered	23
Ochthebius glaber	*Hydraenidae*	*Coleoptera*	*Insecta*	Vulnerable	24
Omocestus femoralis	*Acrididae*	*Orthoptera*	*Insecta*	Vulnerable	12
Orthotylus siuranus	*Miridae*	*Hemiptera*	*Insecta*	Vulnerable	16
Pachygnatha bonneti	*Tetragnathidae*	*Araneae*	*Arachnida*	Vulnerable	25
Paratriodonta alicantina	*Melolonthidae*	*Coleoptera*	*Insecta*	Endangered	11
Pseudamnicola gasulli	*Hydrobiidae*	*Neotaenioglossa*	*Gastropoda*	Vulnerable	10
Silphotrupes punctatissimus	*Geotrupidae*	*Coleoptera*	*Insecta*	Vulnerable	29
Sparedrus lencinae	*Oedemeridae*	*Coleoptera*	*Insecta*	Vulnerable	12
Suboestophora tarraconensis	*Trissexodontidae*	*Pulmonata*	*Gastropoda*	Vulnerable	12
Thorectes valencianus	*Geotrupidae*	*Coleoptera*	*Insecta*	Vulnerable	23
Troglobisium racovitzai	*Syarinidae*	*Pseudoscorpiones*	*Arachnida*	Vulneralbe	11
Unio tumidiformis	*Unionidae*	*Unionoida*	*Bivalvia*	Vulnerable	13
Zabrus pinguis	*Carabidae*	*Coleoptera*	*Insecta*	Vulnerable	12
Zygaena ignifera	*Zygaenidae*	*Lepidoptera*	*Insecta*	Vulnerable	23

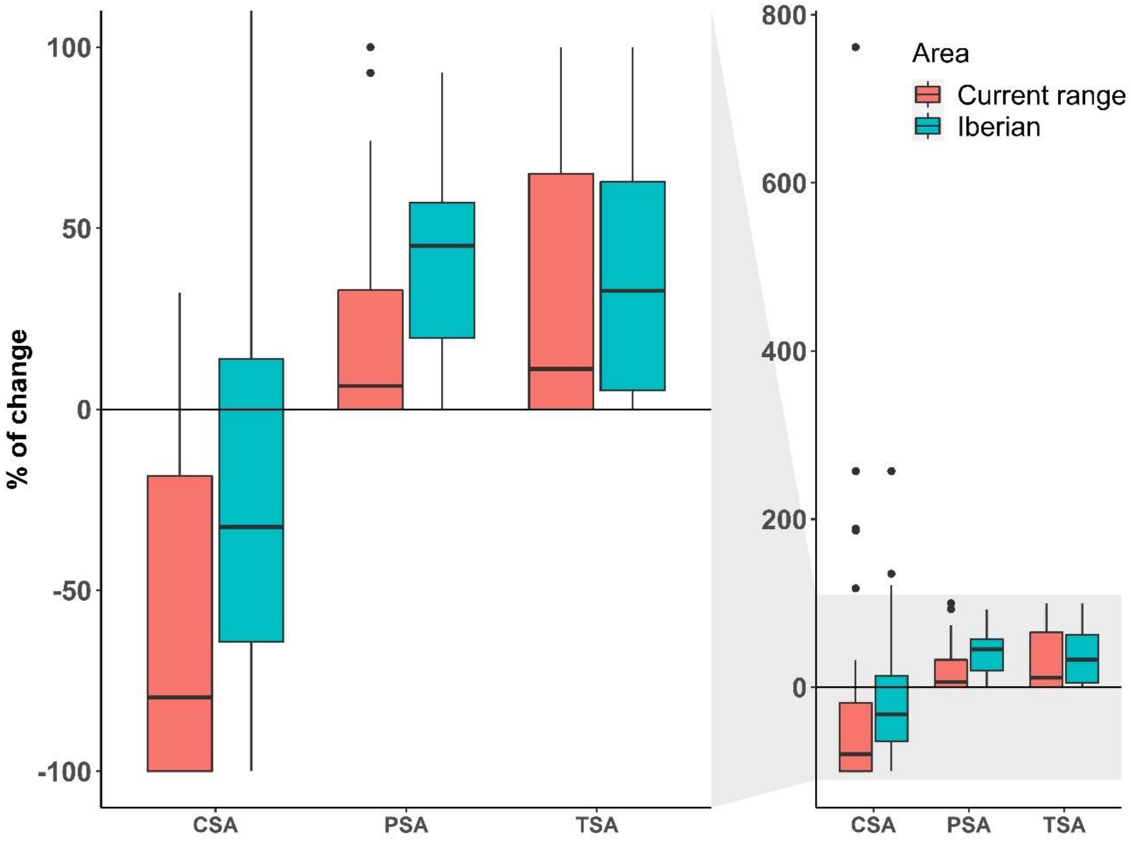
Table 2. Changes in availability of climatically suitable habitat in the future (2070) relative to the present as estimated by three indexes: Change in Suitable Area (CSA), Persistence in Suitable Area (PSA), and Turnover in Suitable Area (TSA). Values correspond to two different climatic scenarios (RCP 4.5 and 8.5) for the whole Iberian Peninsula and the current species range.

		Iberian Peninsula			**Current range**		
Taxa	**RCP**	**CSA**	**PSA**	**TSA**	**CSA**	**PSA**	**TSA**
Apteromantis aptera	4.5	61.34	87.99	45.47	704.61	55.3	93.13
	8.5	93.76	85.77	55.73	932.26	52.07	94.96
Artimelia latreillei	4.5	-19.91	54.8	31.58	-20.52	54.22	31.78
	8.5	-33.77	44.35	33.04	-35.28	43.24	33.19
Baetica ustulata	4.5	-46.82	49.6	6.72	-78.57	21.43	0
	8.5	-70.63	28.17	4.05	-89.29	10.71	0
Berberomeloe insignis	4.5	-28.13	62.58	12.92	-60.47	39.53	0
	8.5	-38.26	52.58	14.83	-67.44	32.56	0
Canariola emarginata	4.5	-44.41	48.03	13.59	-65.67	32.84	4.35
	8.5	-61.2	32.72	15.66	-95.52	4.48	0
Carabus galicianus	4.5	17.56	62.17	47.12	-32.09	27.73	59.17
	8.5	12.34	50.85	54.74	-67.91	3.11	90.29
Carabus ghilianii	4.5	72.76	49.66	71.26	-77.27	10.23	55
	8.5	28.28	37.93	70.43	-100	0	0
Carabus pyrenaeus	4.5	-100	0	0	-100	0	0
	8.5	-100	0	0	-100	0	0
Cephalota deserticoloides	4.5	150	85.71	65.71	150	85.71	65.71
	8.5	514.29	92.86	84.88	457.14	92.86	83.33
Ceratophyus martinezi	4.5	-42.66	41.53	27.57	-64.41	32.54	8.57
	8.5	-64.16	23.8	33.61	-91.87	8.14	0
Coscinia romeii	4.5	-4.7	16.24	82.96	-90.42	0	0
	8.5	-12.82	16.24	81.37	-92.81	0	0
Dericorys carthagonovae	4.5	1.24	83.64	17.38	-9.7	55.22	38.84
	8.5	16.36	83.75	28.02	-11.94	54.48	38.14
Dolichopoda bolivari	4.5	-100	0	0	-100	0	0
	8.5	-100	0	0	-100	0	0
Formica dusmeti	4.5	-11.18	57.27	35.52	-14.09	57.8	32.72
	8.5	-15.51	39.37	53.4	-26.6	39.7	45.92
Hadjina wichti	4.5	-60.14	30.07	24.55	-100	0	0
	8.5	-73.91	23.19	11.11	-100	0	0
Iberodorcadion ferdinandi	4.5	-100	0	0	-100	0	0
	8.5	-100	0	0	-100	0	0
Leptoterna pilosa	4.5	29.3	50.8	60.71	24.36	25.55	79.45
	8.5	75.74	51.88	70.48	85.62	27.68	85.09

Macrothele calpeiana	4.5	-21.14	69.24	12.19	-68.62	30.44	2.99
	8.5	-24.76	63.92	15.04	-83.84	15.93	1.45
Melanopsis cariosa	4.5	-13.04	23.79	72.65	-35.51	0	100
	8.5	-37.34	8.82	85.92	-85.98	0	100
Melanopsis lorcana	4.5	14.6	36.48	68.17	174.76	99.51	63.78
	8.5	63.35	55.62	65.95	205.34	100	67.25
Montserratina martorelli	4.5	-45.31	50	8.57	-59.32	32.2	0
	8.5	-33.59	53.91	18.82	-37.29	38.98	0
Mylabris uhagonii	4.5	103.51	87.75	56.88	154.35	74.03	70.89
	8.5	127.68	85.65	62.38	179.03	71.94	74.22
Norelona pyrenaica	4.5	-100	0	0	-100	0	0
	8.5	-100	0	0	-100	0	0
Ochthebius glaber	4.5	151.24	49.82	80.17	11.63	20.78	81.39
	8.5	138.3	32.18	86.5	-59	1.94	95.27
Omocestus femoralis	4.5	-36.05	63.02	1.45	-84.27	0	0
	8.5	-42.96	55.9	2	-85.39	1.12	0
Orthotylus siuranus	4.5	159.24	74.88	71.12	153.8	74.27	70.74
	8.5	136.97	54.5	77	136.26	56.14	76.24
Pachygnatha bonneti	4.5	-25.29	55.54	25.66	-80.61	0	100
	8.5	-43.59	36.2	35.82	-91.84	0	100
Paratriodonta alicantina	4.5	25.51	61.66	50.87	-100	0	0
	8.5	20.27	39.36	67.28	-100	0	0
Pseudamnicola gasulli	4.5	-84.18	11.39	28	-100	0	0
	8.5	-99.37	0.63	0	-100	0	0
Silphotrupes punctatissimus	4.5	-78.64	5.3	75.19	-92.17	2.32	70.37
	8.5	-82.12	3.64	79.63	-100	0	0
Sparedrus lencinae	4.5	-72.49	26.81	2.56	-90.6	9.4	0
	8.5	-78.08	20.74	5.35	-72.65	23.93	12.5
Suboestophora tarraconensis	4.5	-100	0	0	-100	0	0
	8.5	-100	0	0	-100	0	0
Thorectes valencianus	4.5	-28.76	69.13	2.95	-100	0	0
	8.5	-42.56	55.43	3.51	-100	0	0
Troglobisium racovitzai	4.5	-43.23	56.77	0	-100	0	0
	8.5	-61.45	38.55	0	-100	0	0
Unio tumidiformis	4.5	-61.99	36.57	3.8	-48.32	3.36	93.51
	8.5	-67.57	25.29	22.03	202.01	26.85	91.11
Zabrus pinguis	4.5	-100	0	0	-100	0	0
	8.5	-100	0	0	-100	0	0
Zygaena ignifera	4.5	46.28	22.33	84.74	-86.02	8.6	38.46
	8.5	17.19	10.15	91.34	-96.24	0.54	85.71

Figure 1. Changes in availability of climatically suitable habitat in the future (2070, RCP 8.5) relative to the present as estimated by three indexes: Change in Suitable Area (CSA), Persistence in Suitable Area (PSA), and Turnover in Suitable Area (TSA). Red boxplots show the change in the total Iberian Peninsula and green values to the species range.

Figure 2. Three examples of species distribution projections to 2070 under RCP 8.5: a) *Baetica ustulata*, mountain species categorized as ”loser”; b) *Omocestus femoralis* , northern shift of the suitable habitat and also categorized as a ”loser”; c) *Cephalota deserticoloides,* arid-adapted species categorized as a ”winner”. White colours show unsuitable areas for both present and future conditions; orange colour reflects the suitable area at the present conditions but that will not suitable in the future; blue colour indicates currently unsuitable suitable area that becomes suitable in the future; and grey colour represents suitable areas for both present and future conditions. An example of the computation of Change in Suitable Area (CSA), Persistence of Suitable Area (PSA) and Turnover in Suitable Area (TSA) is provided in d). Black lines show the training area of each species used in the modelling.



% of change
100
50
0
-50
-100
CSA
PSA
TSA
800
600
400
200
0
Area
Current range
Iberian

Figure 1.

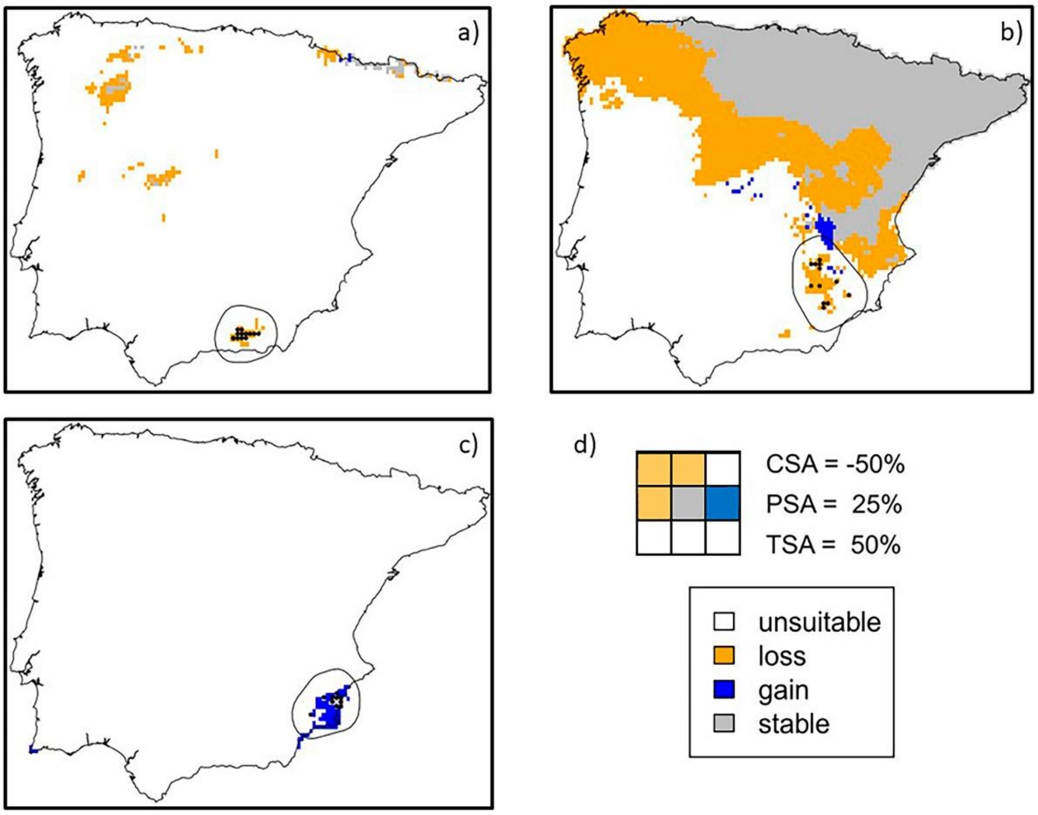


Figure 2.