Bulletin of Insectology ***70*** *(2): 189-200, 2017*
ISSN 1721-8861

Using Maximum Entropy Modeling (MaxEnt) to predict future trends in the distribution of high altitude endemic insects in response to climate change

Fabrizia Urbani, Paola D'Alessandro, Maurizio Biondi
Department of Health, Life and Environmental Sciences, University of L'Aquila, Italy

Abstract

This study analyzes the possible usefulness of "species distribution models" (SDMs) using "Maximum Entropy Modeling" (MaxEnt) software to investigate the effects of climate change, under both current and projected conditions, on the distribution of 10 endemic Italian insect species (Coleoptera and Orthoptera) associated with high altitude areas in the Central Apennines. Twenty-two environmental variables are used as potential predictors of species habitat suitability. Climatic conditions exert strong control over the geographic distribution of species and MaxEnt highlights that the most influential factors mainly are fluctuation in temperature and variation in weather events typically associated with high altitude environments. The extent of suitable areas is calculated by the "suitability status change index" (SSCI) and differences in habitat suitability between current and future conditions are compared. Although the most optimistic future scenario (RCP2.6) is used, the results obtained show a serious decline in suitable habitat for vulnerable and sensitive species: in particular, the suitable habitats of *Italohippus monticola*, *Italopodisma fiscellana*, and *Luperus fiorii* will be heavily reduced, whereas a total loss (100%) of suitable habitat will be experienced by *Trechus hummleri*. In addition, through the centroid analysis, some species (*Italohippus monticola*, *Italopodisma costai*, *Otiorhynchus sirentensis*, and *Trechus cerrutii*) show a slight "virtual" gain and a "southeastern shift" of their suitable habitat. Species distribution models can be extremely helpful to identify and analyze the cause of the fragmentation and contraction distribution. From the conservation point of view, the endemic taxa generally represent very vulnerable elements, so correct and farsighted actions are indispensable for the protection of particularly sensitive habitats harbouring them, such as Central Apennines that represent one of the most important hotspot of biodiversity for high altitude species, especially for insects, in Europe.

Key words: species distribution modeling, MaxEnt software, Coleoptera, Orthoptera, Italy, Apennines, climate change, conservation.

Introduction

Species distribution models (SDMs) are receiving such an increase in attention in conservation and biogeographical studies, that they are currently one of the most widely used scientific approaches for the identification of potential climate-change effects on biodiversity (Beck, 2013; Berzitis *et al*., 2014; Chłond *et al*., 2015). These models are successfully and widely applied to assess the ecological and evolutionary forces that shape the geographical distribution of species and the suitability of their habitat (Elith *et al*., 2006; Bosso *et al*., 2013; Zhu *et al*., 2013). Species distribution models are based on the relationship between the observed species distribution (through occurrence records) and the environmental variables determining not only suitable habitats, but also limiting barriers. In addition, these approaches can be useful to predict suitable habitats for species in areas where their distribution is not completely known.

Species distribution models are widely used in many ecological, biological and biogeographical applications to predict past, current and future species distributions (Guisan and Thuiller, 2005). To study the expected impact of climate change on biodiversity, however, it is necessary to know how environmental variables will evolve in future, and how habitats and species distributions transform in relation to climate change.

In many cases climatic conditions have been reported as major factors influencing the geographical distribution of global biodiversity (Pearson and Dawson, 2003; Thomas *et al*., 2004; Araújo and Pearson, 2005; Baselga and Araújo, 2009). Climate change has been postulated to be one of the major causes of the geographic shifting of suitable environmental conditions both for animal and vegetable species (Parmesan and Yohe, 2003; Araújo *et al*., 2011; Chen *et al*., 2011; Reif and Flousek, 2012; Brambilla *et al*., 2014; Carta, 2014; Hu *et al*., 2015; Remya *et al*., 2015), and as one of the largest threats to global biodiversity, due to the alteration caused to the habitat of many species.

Several studies on different predictive spatial distribution approaches have in fact demonstrated the critical role of the impacts of climate change on species distributions (Rebelo *et al*., 2010; Bellard *et al*., 2012; Devictor *et al*., 2012; Gastón and García-Viñas, 2013; Travis *et al*., 2013; Chen *et al*., 2015; Hu *et al*., 2015) and in particular on sensitive or threatened species distributions like those endemic (Escalante *et al*., 2009; Kumar and Stohlgren, 2009; Bosso *et al*., 2013; Kamino *et al*., 2012; van Gils *et al*., 2012; Urbani *et al*., 2015).

Modeling studies are of great importance in biological conservation; their predictive capabilities shed light on several issues, such as reduction of the distribution area of protected species, or the possible extension of invasive species (Beck, 2013; Fourcade *et al*., 2014).

Mountain ecosystems are subjected to relatively low human impacts, yet they show high sensitivity and vulnerability to the impact of climate change (Brunetti *et* *al.*, 2009; Brambilla *et al.*, 2014; Ramirez-Villegas *et al.*, 2014). Variation in the structure and distribution of habitats, mainly due to an increase in temperature and change in rainfall patterns, with variation in the intensity and frequency of extreme events, threaten the most sensitive species where they occur, e.g. the raising of the tree line affects species associated with high altitudes. Through SDMs it is possible to evaluate the potential availability of suitable habitat for many species in a given area and consequently estimate eventual modifications in their future distribution (Aguilar *et al.*, 2015; Ehrlén and Morris, 2015).

To investigate the effects of climate change, under both current and projected conditions, on some insect species associated with high altitudes, we used a species-climate envelope modeling approach on a selected group of Coleoptera and Orthoptera endemic to Italy in the Central Apennines. This faunal component has experienced differentiation processes and geographic and ecological isolation as a result of complex turnover of palaeoclimatic vicissitudes that have affected the Apennines during the Pliocene-Pleistocene glaciations. The Central Apennines in particular, played a fundamental role as a refuge area in the Quaternary, becoming an important current biodiversity hotspot for many endemic species and subspecies, generally occurring in small and fragmented populations (La Greca, 2002; Stoch, 2007; Fattorini, 2010; Biondi *et al.*, 2013).

Materials and methods

Study area

The study area (figure 1) includes the peninsular part of Central Italy, located at altitudes equal to or higher than 1400 m a.s.l., encompassing the main mountain massifs of the Central Apennines. Vegetation zones are mostly represented from Apennine deciduous montane forests (mainly beechwoods) to montane shrublands and grasslands (Pedrotti and Gafta, 2003), while the climatic region is the "Mediterranean warm temperate mountainous climate" (TM4 of Constantini *et al.*, 2013).

Species databases

Ten endemic Apennine insect species, with distribution ranges above 1400 m a.s.l., were considered: order Orthoptera: 3 Acrididae [*Italohippus monticola* (Ebner) (IUCN, 2016: Endangered), *Italopodisma costae* (Targioni-Tozzetti) (IUCN, 2016: Least Concern), and *Italopodisma fiscellana* (La Greca) (IUCN, 2016: Endangered)]; order Coleoptera: 4 Chrysomelidae [*Longitarsus springeri* Leonardi, *Luperus fiorii* Weise, *Oreina sibylla* (Binaghi), and *Psylliodes biondii* Leonardi], 2 Carabidae [*Trechus hummleri* Jeannel and *Trechus cerrutii* Focarile], 1 Curculionidae [*Otiorhynchus sirentensis* D'Amore-Fracassi]. For the last species we only considered the strictly endemic populations to the Central Apennines attributed to the typonominals. None of the species of Coleoptera considered is included in IUCN or national red lists.

The occurrence data (supplemental table S1) were generated:

- for Coleoptera Chrysomelidae, both from unpublished data (M. Biondi, personal data) and from a critical bibliographic screening including: Biondi, 1990; Biondi and De Nardis, 2001; Biondi and Di Casoli, 1996; Bologna, 1985; Bologna *et al.*, 1992; Daccordi and Ruffo, 1976; D'Alessandro and Biondi, 2007; Fogato, 1978; Gruev, 2000; Leonardi, 1975; 2007; Magistretti and Ruffo, 1961; Ruffo and Stoch, 2006; Biondi *et al.*, 2013;
- for Coleoptera Carabidae (Ruffo and Stoch, 2006) and unpublished data (A. Casale and P. Magrini, personal data);
- for Coleoptera Curculionidae (Ruffo and Stoch, 2006);
- for Orthoptera Acrididae (Ruffo and Stoch, 2006) and unpublished data (B. Massa, personal data).

Each record was reported in the form of geographical coordinates (UTM-WGS84 reference system) (supplemental table S1) and distribution maps were generated with ESRI ArcGis 10.0 software.

Generally, only occurrence data collected or confirmed after 1975 were considered in our analysis.

Environmental variables

Two types of environmental variables were used to parameterize our models (supplemental table S2): a) bioclimatic variables (BIO1-BIO19), extracted from the WorldClim-Global Climate database (Hijmans *et al.*, 2005; http://www.worldclim.org), consisting mainly of annual and seasonality trends in temperature and precipitation; b) topographic variables relative to land morphology, such as elevation (ALT), aspect (ASPECT) and slope (SLOPE).

Elevation data (ALT) was obtained from the WorldClim website and was used to generate the variables SLOPE, that is the incline or steepness of the surface, and ASPECT, that is the compass direction that a topographic slope faces, using the "surface tool" in ArcGIS® Spatial Analyst.

Each predictor variable dataset required prior manipulation to be used in Maximum Entropy Modeling (MaxEnt), because they must have the same geographic bounds, cell size and coordinate system. All downloaded rasters have a world extension and so it necessary to reported them to the same spatial characteristics through the "Extract by Mask" tool (in Arctoolbox of ArcGis). In addition, each climate layer raster has been transformed into ASCII raster grid to be used in Maxent software. All environmental variables were reported with a 30 arc-second (approximately 1 km) spatial resolution, the highest resolution available by WorldClim.

Species Distribution Model (SDM)

To predict the potential distribution of the analyzed species, SDM tools were used in our study. Climate envelope models for each species were performed with MaxEnt (Maximum Entropy Modeling) version 3.3.3k (Phillips *et al.*, 2006). Maximum Entropy Modeling software estimates the most uniform distribution, subject to constraints imposed by the observed spatial distribution of the species and environmental conditions (Phillips *et al.*, 2006).

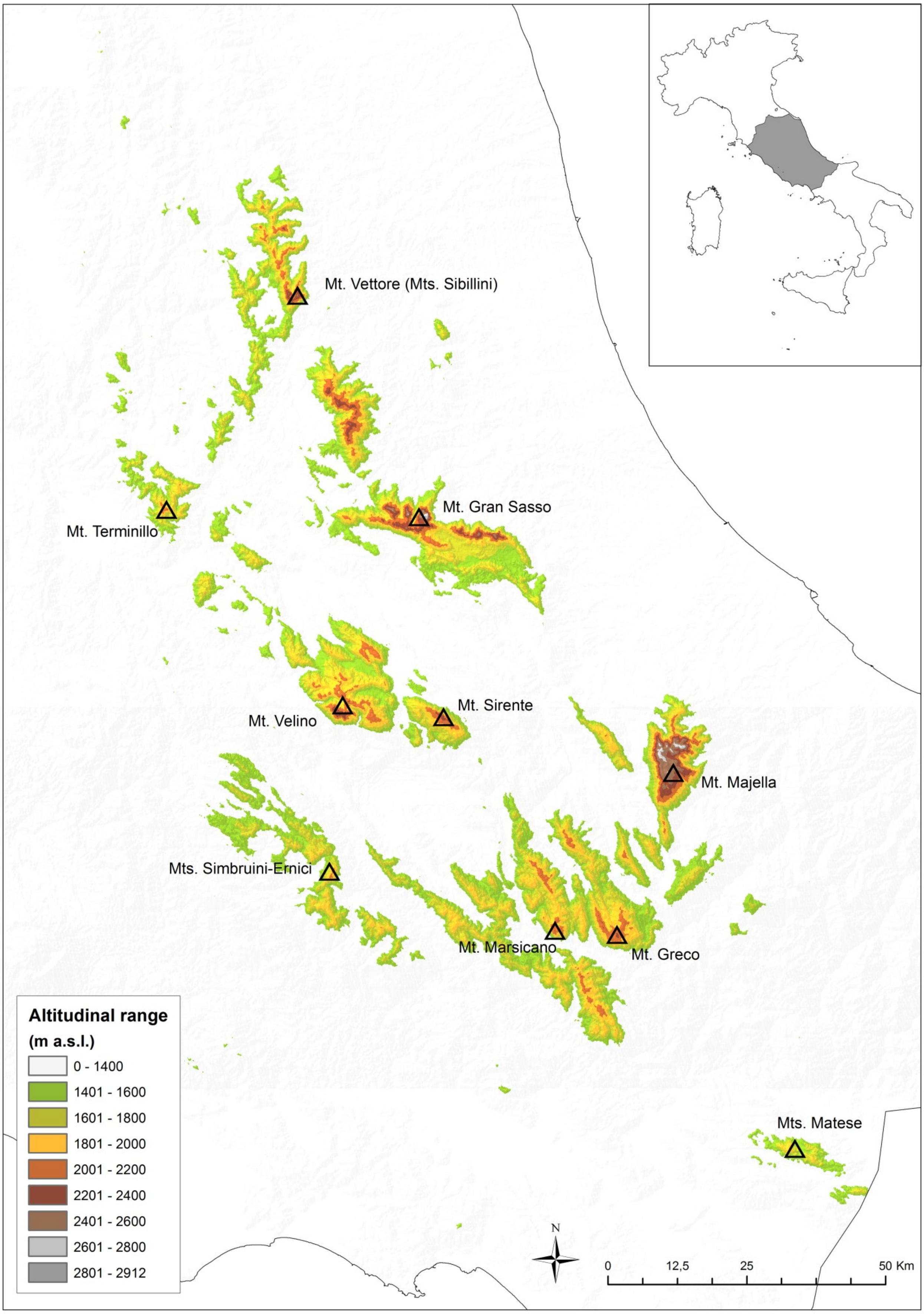

Figure 1. Study area: Central Apennines with the areas located at altitudes equal to, or higher than, 1400 m above sea level (in colour). The symbol (Δ) indicates the main massif for each mountain district.

MaxEnt uses presence-only data as input to predict the potential distribution of a given species. This approach allows taking the greatest part of datasets sourced from museums, collection reports or online databases, into consideration (Guisan *et al*., 2013; Aguilar *et al*., 2015; Urbani *et al*., 2015).

The literature indicates that this modeling method is one of those most commonly used. We chose it because it produces robust results, even with sparsely and irregularly sampled data, as it is less sensitive to the number of occurrence records (Elith *et al*., 2006; Hernandez *et al*., 2006; Pearson *et al*., 2007).

The parameter settings used in our analyses are: convergence threshold (0.00001), replicates (5), replicate run type (cross-validate), regularization multiplier (1), maximum number of iterations (500), random test percentage (25); other parameters were retained with their default settings. Background was created using 10,000 random points, automatically generated by MaxEnt. The duplicate presence records per cell were removed and the output grid format was set to "logistic".

Tenth percentile training threshold (10P) (Freeman and Moisen, 2008) was adopted to convert maps from suitability indices to presence/absence. This threshold was chosen because it is a conservative approach suggested for those datasets collected with non-standardized methods (e.g. museum or collection reports) or by different collectors or observers over a long time (Rebelo *et al*., 2010; Bosso *et al*., 2013). It is important to underline, in order to reduce the number of false positives, that it is preferable to choose lower threshold values. False positives can be the result of biotic and abiotic factors that obstruct a species to occupy a suitable area (e.g. dispersal limitations); conversely, false negatives may be due to inaccuracies in the model or even the choice of a threshold too high (Urbani *et al*., 2015). Binary maps where thereby generated to depict potential distribution maps that identify different levels of habitat suitability for each species. All pixels with a value under the selected threshold were assigned a value equal to zero (0) and represent the unsuitable areas. To estimate model performance, we used the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) plot, which evaluates the aptitude of a model to discern the areas where a given species occurs (1 = perfect predictive ability) from the areas where it is absent (0 = no predictive ability) (Elith *et al*., 2006; Phillips *et al*., 2006; Lobo *et al*., 2007; Phillips and Dudík, 2008).

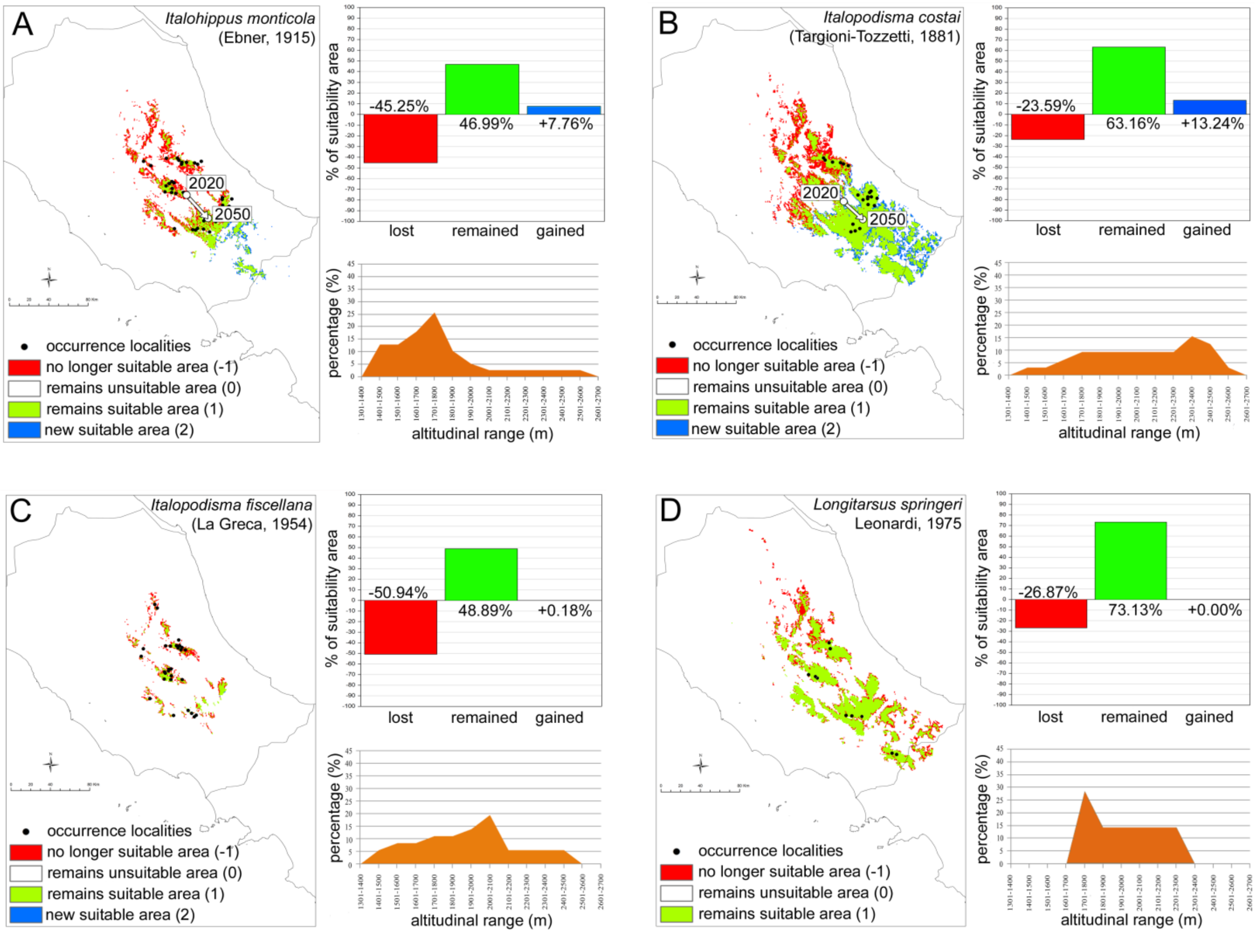

Figure 2. *I. monticola* **(A)**, *I. costai* **(B)**, *I. fiscellana* **(C)**, *L. springeri* **(D)**. Current and predicted distribution (white arrow depicts the direction of a possible shift in suitable habitat in 2050). Percentage of suitable habitat between current and future conditions: no longer suitable area (red); remains suitable area (green); new suitable area (blue). Current altitudinal range.

Each of the 22 variables used was evaluated for its contribution to the model and the response curves built by MaxEnt were reported for the most significant three. Distribution maps were produced for each species, reporting the probability of presence according to a percentage scale.

Future climate data

Future predictive distribution maps were also generated at 30s resolution, using the 19 bioclimatic variables (BIO1-19) downloadable from the WorldClim website. Among the different Global Climate Models (GCMs) available for future predictions, the CNRM-CM5 climate model (Voldoire *et al.*, 2013) was preferred. This model was generated by the Centre National de Recherches Météorologiques (France) under four climatic scenarios, represented by the Representative Concentration Pathways: RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, where the numbers refer to the radiative forcings measured in watts per square metre (W/m^2). RCP 2.6 was chosen for our analysis, because this scenario is the most conservative and ambitious pathway enough to be often considered as not realistic (van Vuuren *et al.*, 2011). The purpose of our analysis is therefore to assess if this demanding pathway should be sufficient to avoid possible large effects of climate change on the future distribution of the species considered, through extensions or reductions of their areal. RCP 2.6 assumes, indeed, 'aggressive' mitigation strategies that should cause global greenhouse gas emissions to start decreasing after about a decade, in order to drop to zero level by 2070 (IPCC, 2013).

To compare differences in suitable habitat between current and future conditions and evaluate possible effects of climate change on the distribution of each species, we are referring to the "suitability status change index" (SSCI) proposed by Ceccarelli and Rabinovich (2015), where the values obtained by the subtraction between future and current suitability areas were considered. Based on this index, the output maps were reclassified as binary maps, indicating with "1" the possible occurrence (i.e. the values falling within the suitable habitat) and with "0" the absence (i.e. the values falling within the range under the threshold value). For the future suitability values, the occurrence is indicated with "2" instead. The possible changes between current and future suitability status can be: "no longer suitable area" (-1) (currently suitable areas that will not remain the

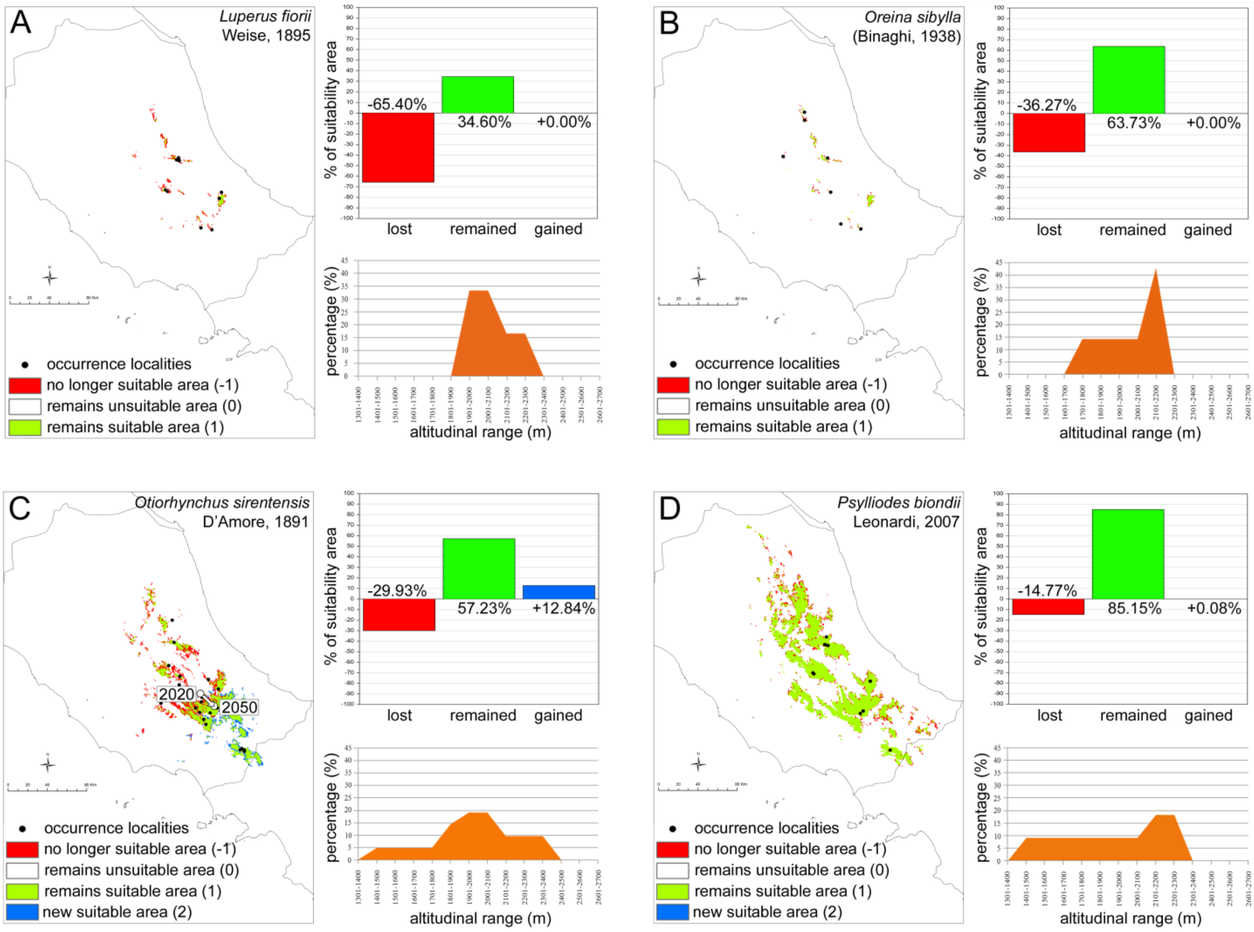

Figure 3. *L. fiorii* **(A)**, *O. sibylla* **(B)**, *O. sirentensis* **(C)**, *P. biondii* **(D)**. Current and predicted distribution (white arrow depicts the direction of a possible shift in suitable habitat in 2050). Percentage of suitable habitat between current and future conditions: no longer suitable area (red); remains suitable area (green); new suitable area (blue). Current altitudinal range.

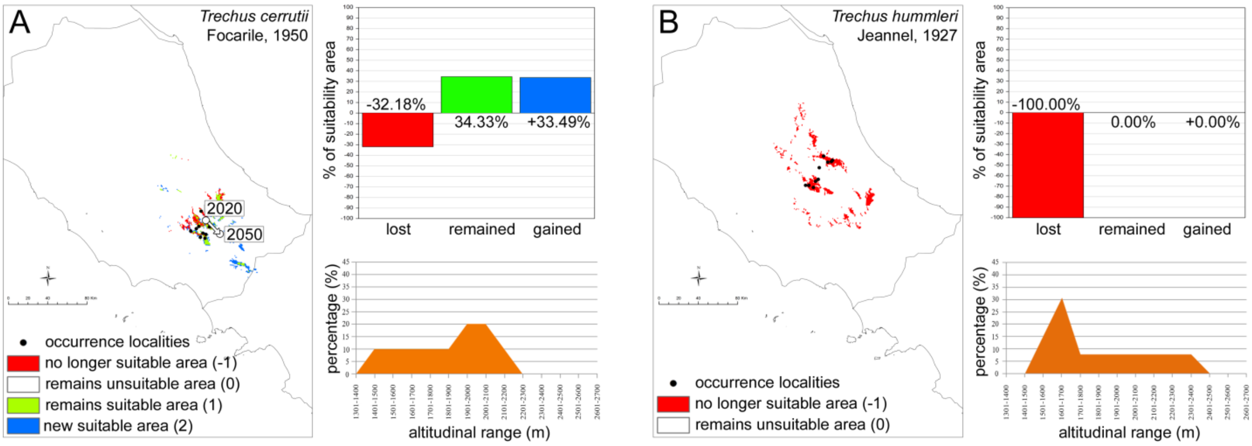

Figure 4. *T. cerrutii* **(A)**, *T. hummleri* **(B)**. Current and predicted distribution (white arrow depicts the direction of a possible shift in suitable habitat in 2050). Percentage of suitable habitat between current and future conditions: no longer suitable area (red); remains suitable area (green); new suitable area (blue). Current altitudinal range.

same in the future), “remains unsuitable area” (0) (unsuitable both currently and under future climatic conditions), “remains suitable area” (1) (suitable both currently and under future conditions), and “new suitable area” (2) (currently unsuitable but becoming suitable under future conditions) (supplemental table S3).

The extent of suitable areas, in current and future scenarios, was calculated considering the number of “colored” pixels, and multiplying them by cell size values; the results were reported as percentages (figures 2-4).

The final predictive maps were created taking into consideration the potential suitability areas for each species at two different times, present-time and 2050 in the scenario RCP 2.6, identifying those areas that will be lost, gained or remain unchanged in the future climate scenario considered. In addition, we have also calculated possible range shifts for each species, using ArcGis tools, by comparing eventual different positions of the relative two centroids meant as the central points of the current and the future distribution (Aguilar *et al.*, 2015).

Finally, the occurrence data for each species were interpolated with the rasters of the bioclimatic variables, to highlight positive or negative trends of the variation between current time and the 2050’s.

Results

The model evaluation provided satisfactory results with AUC mean values higher than 0.969, indicating a high power of MaxEnt in predicting potential habitat for the ten insect species analyzed. Presence data showed no spatial autocorrelation for the ten species considered, with Moran’s Index comprised between −0.001 and 0.261 (table 1).

In table 1, are reported the estimates for the relative contributions of the most significant environmental variables used by MaxEnt for building the models and data helpful to interpret the analyses proposed. Overall, the variables providing the highest contribution to the potential distribution models obtained are BIO3 (isothermality), BIO18 (precipitation of warmest quarter) and ALT (altitude) (table 1), with correlation values: BIO3-BIO18 = −0.23; BIO3-ALT = −0.46; BIO18-ALT = 0.67.

By analyzing table 1 and supplemental figure S1, we note how the three Orthoptera species considered (*I. monticola*, *I. costai* and *I. fiscellana*), characterized by a similar ecological condition associated with the xeric habitats at high altitudes (Massa *et al.*, 2012), are regulated by exactly the same variables (BIO3, ALT and BIO18).

In eight of the ten species considered (3 Orthoptera and 5 Coleoptera), BIO3 is the most important variable contributing to their environmental compatibility. These eight species show a habitat suitability inversely proportional to the increase of the BIO3 values, indicating a high sensitivity to large fluctuations in temperature. In addition, by analyzing table 1 and the response curves in supplemental figure S2-S3, we note how the optimum range (18-20%) of this variable corresponds to a probability of presence of 95-98%, which then decreases and reaches “zero” suitability for higher values (>28-30%). The two remaining Coleoptera: Carabidae species, *T. cerrutii* and *T. hummleri*, are typical representatives of the edaphic fauna; for the first species BIO3 contributes significantly to its habitat suitability (24%), but not for the latter (0%), which is instead regulated mainly by BIO18 (23.4%), BIO9 (22.3%) and BIO8 (17.0%) (table 1, supplemental figure S1), with correlation values: BIO8-BIO9 = 0.01; BIO8-BIO18 = 0.18; BIO9-BIO18 = −0.89.

About ALT, the increasing value of this variable generally indicates a gain in the potential suitable habitat for most species considered, showing an optimum range at altitudes higher than 1800-2000 m (table 1, supplemental figure S2-S3).

Regarding the variable BIO18, precipitation values show a peak of about 60-70% of probability of presence, corresponding with about 180-200 mm, for *I. monticola*, *I. costai*, *I. fiscellana*, *O. sirentensis* and *T. hummleri* (table 1, supplemental figure S2-S3).

Table 1. Data from Maximum Entropy (MaxEnt) models for species: A) 10th percentile (10P) training presence logistic threshold values; B) AUC mean values; C) Moran's Index values; D) most significant three variables by MaxEnt for each species, with unit of measure, percent contribution, optimal range and "zero" suitability values.

Species	(A) 10P	(B) AUC (mean)	(C) Moran Index	Variables	Unit of measure	Contribution (%)	(D) Optimal range	Probability of presence (mean%)	"Zero" suitability
Italohippus monticola	0.182	0.987	0.191	BIO3	/	33.9	18-20	98	>34
				ALT	m	20.0	2000	68	<500
				BIO18	mm	19.6	200	70	<60 or >330
Italopodisma costai	0.076	0.982	0.221	BIO3	/	47.4	18-20	98	>36
				BIO18	mm	15.4	200	68	<40 or >400
				ALT	m	12.4	>1800	68	0
Italopodisma fiscellana	0.283	0.994	0.281	BIO3	/	42.9	18-20	96	>30
				ALT	m	20.1	1900	70	<500
				BIO18	mm	16.2	200	71	<100 or >350
Longitarsus springeri	0.138	0.983	−0.001	BIO3	/	33.0	18-20	98	>34
				ALT	m	20.1	>2500	>73	0
				BIO12	mm	9.2	0-300	67	>2500
Luperus fiorii	0.402	1.000	0.000	BIO3	/	74.5	17-19	96	>28
				BIO9	°C	13.2	−14/−10	83	>20
				BIO18	mm	6.3	0-40	51	>600
Oreina sibylla	0.517	0.982	−0.001	BIO3	/	68.4	17-19	97	>28
				BIO19	mm	13.6	0-80	75	>600
				BIO2	°C	9.9	3.0-3.8	95	>7
Otiorhynchus sirentensis	0.078	0.985	0.094	BIO3	/	46.3	18-20.5	95	>32
				ALT	m	21.5	2000	70	0
				BIO18	mm	12.7	180	65	<50 or >400
Psylliodes biondii	0.065	0.976	−0.001	BIO3	/	69.4	18-20	97	>32
				BIO19	mm	8.3	20-80	71	>750
				ALT	m	7.0	>2500	>73	0
Trechus cerrutii	0.472	0.997	0.224	BIO8	°C	43.6	1	69	<−10 or >10
				BIO3	/	24.0	18-20	97	>32
				BIO19	mm	12.0	170	55	>400
Trechus hummleri	0.458	0.969	0.058	BIO18	mm	23.4	220	63	<40 or >400
				BIO9	°C	22.3	−2.5	58	<−10 or >20
				BIO8	°C	17.0	3.5	71	<−10 or >15

Table 2. Mean differences of bioclimatic variables for species between current time and the 2050's. Symbols for temperature variables: ≈ around zero; ↑ between 0.1 and 1.0; ↑↑ between 1.1-3.0; ↑↑↑ between 3.1-5.0; ↑↑↑↑ > 5.1. Symbols for precipitation variables: ≈ around zero; ↑ between 1.0 and 10.0; ↑↑ between 10.1-30.0; ↑↑↑ between 30.1-50.0; ↑↑↑↑ > 50.1; ↓ between −1.0 and −10.0.

	trend	*Italohippus monticola*	*Italopodisma costai*	*Italopodisma fiscellana*	*Longitarsus springeri*	*Luperus fiorii*	*Oreina sibylla*	*Otiorhynchus sirentensis*	*Psylliodes biondii*	*Trechus cerrutii*	*Trechus hummleri*
diff BIO1 (°C)	1.358	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
diff BIO2 (°C)	0.014	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈
diff BIO3 (%)	−0.007	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈
diff BIO4 (°C)	0.030	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈
diff BIO5 (°C)	1.788	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
diff BIO6 (°C)	0.895	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
diff BIO7 (°C)	0.893	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
diff BIO8 (°C)	2.405	↑↑	↑↑↑	↑↑	↑↑	↑↑↑	↑↑	↑↑	↑↑	↑↑↑	↑↑
diff BIO9 (°C)	1.462	↑↑	↑↑	↑	↑↑	↑	↑↑	↑↑	↑↑	↑↑↑	↑↑
diff BIO10 (°C)	1.751	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
diff BIO11 (°C)	0.949	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
diff BIO12 (mm)	54.294	↑↑↑↑	↑↑↑↑	↑↑↑↑	↑↑↑	↑↑↑↑	↑↑↑↑	↑↑↑	↑↑↑↑	↑↑↑	↑↑↑↑
diff BIO13 (mm)	14.298	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
diff BIO14 (mm)	−3.022	↓	↓	↓	≈	↓	↓	≈	↓	↑	↓
diff BIO15 (%)	0.011	≈	≈	≈	≈	≈	≈	≈	≈	≈	≈
diff BIO16 (mm)	11.787	↑↑	↑↑	↑↑	↑	↑↑	↑↑	↑↑	↑↑	↑	↑↑
diff BIO17 (mm)	10.048	↑↑	↑↑	↑	↑	↑↑	↑	↑↑	↑	↑	↑↑
diff BIO18 (mm)	20.031	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
diff BIO19 (mm)	6.332	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑

For values higher than 200 mm, the increase of precipitation values generally involves a clear reduction of the environmental compatibility. Therefore BIO18, that provides total precipitation during the warmest three months of the year, can supply helpful information on how such environmental factors may affect species seasonal distributions (O'Donnel and Ignizio, 2012).

Comparing temperature and precipitation values between current time and the 2050's (table 2), we see how the future variations of these variables will reach extreme conditions. The values of all temperature variables tend to generally increase (e.g. BIO1: annual mean temperature) and the most marked growth is expected for BIO8 (mean temperature of wettest quarters), BIO5 (max temperature of warmest month) and BIO10 (mean temperature of warmest quarters). As for the precipitation variations, we notice a strong increase of BIO12 (annual precipitation), and smaller increases of BIO13 (precipitation of wettest month), BIO18 (precipitation of warmest quarters), and BIO19 (precipitation of coldest quarter). Conversely, reductions of precipitation are predicted for BIO14 (precipitation of driest months), so exacerbating the differences between the dry and wet periods.

When raster cell counts between current and future conditions are compared, differences between the models are evident. The steps from the current to the future suitable habitat for each species analyzed are reported in figures 2-4, highlighting those areas that will be lost, gained or remain unchanged. The estimate of suitable areas, obtained from threshold spatial predictions of probability, is displayed as percentages.

The model projection for the year 2050 reveals that suitable habitats for all species analyzed will be reduced, the minimum being a limited loss of suitable habitat (figures 2-4). Serious losses of suitable habitat mostly concern: *I. monticola* (−45.25%) (figure 2A), and *I. fiscellana* (−50.94%) (figure 2C), both are orophilous species living in alpine meadows and mountain pastures up to 2500 m in the Central Apennines (Massa *et al*., 2012); *L. fiorii* (−65.40%.) (figure 3A), a strictly alpine species, with an altitudinal range between 1900-2300 m, mainly associated with high pastures and contiguous scree slopes (M. Biondi, personal data).

The predicted complete loss of suitable areas for *T. hummleri* in 2050 (figure 4B) could be due to the large variation in temperature during the next 30 years (BIO1, BIO5, BIO8-10) and the pluviometric variables (BIO12, BIO13, BIO16-18) regulating its distribution (table 2). These variations could have an increased effect at lower altitudes where this beetle preferably lives (optimum 1600-1700 m) (figure 4B). The closely related *T. cerrutii* is associated with higher altitudes (optimum 1900-2100 m) (figure 4A), although its current distribution sites will be undergoing larger increases in temperature (i.e. BIO8-BIO9) and similar pluviometric variations in the near future based on our model, this species seems respond better to these variations, shifting its distribution towards the south-east (figure 4A).

Predictions of habitat loss should be considered as very close to a "real" phenomenon, as climatic and ecological conditions become incompatible and species fail to show resilience, they will move towards extinction. By contrast, "virtual" gains only indicate theoretical potential extensions of suitable areas, suggested by the model for a given species, but they could never be reached or occupied by the species. Our analyses suggest how *I. monticola* (figure 2A), *I. costai* (figure 2B), *O. sirentensis* (figure 3C), and *T. cerrutii* (figure 4A) show a slight "virtual" gain due to the "shifting" of their suitable habitat. These possible "shiftings" of suitable areas were highlighted through the centroid analysis, which shows how they move from the current situation to future scenarios, generally toward the southeast, concerning limited areas (over 1400 m) of the southern area of Central Apennines, mainly Mt. Marsicano (Abruzzo, Lazio and Molise National Park) and Matese. Losses of suitable areas were instead predicted for all species particularly in the Northern sectors of the Central Apennines (Mts. Sibillini).

By analyzing table 1, we can observe how the geographical ranges of *L. springeri* (figure 2D), *L. fiorii* (figure 3A), and *O. sibylla* (figure 3B), will be in contraction without any minimal expansion in the projection to 2050s, showing rather a raising towards high altitudes, facing further reduction and fragmentation of their habitat.

Discussion and conclusions

Due to the limited geographic distribution and the specific ecological conditions characterizing them, endemic taxa generally represent very vulnerable elements. From the conservation point of view, therefore, the prediction of their potential distribution area, mainly in case of threatened species, represents an important tool to understand the environmental factors that could influence their survival and to contribute to the identification of priority actions for their protection (Aguilar *et al*., 2015; Brambilla *et al*., 2014; Ramirez-Villegas *et al*., 2014; Travis *et al*., 2013). In fact, analyzing the causes of the fragmentation and contraction of species distributions allows us to develop possible strategies to try to halt, slow down or reverse negative trends.

Although in the recent past (Stoch, 2006), the current climatic factors have been considered to be poorly correlated and statistically insignificant factors in influencing numerically and compositionally the endemic component of the Italian fauna, they appear instead to grow considerably in importance in the light of current data.

Based on our analysis, the environmental variables that will influence future suitable areas for the endemic species analyzed seem mostly to be represented by “isothermality” (BIO3), revealing the high vulnerability of species associated with high altitudes to strong and large fluctuations in temperature and the severity of extreme weather events (Bisi *et al*., 2015).

Elevation and precipitation variation are also important variables shaping species distribution (van der Putten *et al*., 2010). Elevation is, and will remain, a significant factor with a constraining role for several high-altitude species. Variation in the intensity and frequency of orographic precipitation, especially regarding the increase in precipitation in the warmer and wettest months and the decrease in the driest months, will consistently affect the faunal component associated with high altitudes and result in a reduction in environmental compatibility.

Orophilous species exhibit limited distribution and constrained ecological adaptability, which can make them highly susceptible to the smallest variation in climate. Losses, fragmentations and/or a progressive rise in altitude of suitable habitat, the scarce ability to migrate to new sites, and the possible interspecific competition with species from lower altitudes, are important factors for the survival of high-altitude species (Parmesan, 2006).

By our analysis, a projection RCP 2.6 to 2050s could cause a strong decrease in the amount of suitable area for all the analyzed species living at high altitudes in the Central Apennines, even leading some of them to the brink of extinction, notwithstanding the fact that the projection considered is the most optimistic. Our final models reveal, in fact, how even a moderate increase in temperature may affect animal biodiversity in high altitude environments.

Many species living at lower altitudes could move towards higher altitudes to contrast the effects of global warming and find new optimal conditions for their survival, but those species already associated with high-altitudes have no escape route to avoid extinction, unless they move to suitable habitats in adjacent areas. This possibility is also suggested by MaxEnt for species such as *I. costai*, *I. monticola*, *T. cerrutii* and *O. sirentensis*, that could shift their distribution southwards, where they could find more suitable environments. This shift in a south-easterly direction, although being only theoretic, could actually be possible thanks to the presence of intermediate valleys at high elevations that could favour the faunal exchange among mountain groups in Central Apennines. Conversely, no shifting could be possible to the North of the Central Apennines, because of the interruption of ecological continuity due to the presence of only large areas at low and medium altitudes.

Our analyses suggest possible evolution of environmental and climatic changes but, obviously, do not provide predictions in an absolute way. It is therefore also necessary to interpret these results on the basis of autoecological and sinecological information, such as dispersal capabilities, trophic specialization, meiopterism, philopatric behaviour, and/or vicariance events (Piper and Compton, 2010; Biondi *et al*., 2013), but also on factors such as the over-simplification of ecosystems and progressive human settlement, which tend to accelerate the impoverishment of biodiversity, especially in very sensitive environments, e.g. those at high altitudes. In conclusion, in the light of the obtained results, we underline the importance of including the application of predictive models to hypothesize future climate scenarios into existing preservation strategies, and to develop a global management plan of action in order to apply conservation measures. Correct and farsighted actions are indeed indispensable for particularly sensitive habitats and vulnerable species, in particular for areas as Central Apennines that represent one of the most important hotspot of biodiversity for high altitude species, especially for insects, in Europe (Biondi, 2017).

Acknowledgements

We are grateful to our colleagues and friends: Achille Casale and Paolo Magrini, for their help and useful information on *Trechus cerrutii* and *T. hummleri*. and Bruno Massa, for his suggestions on Acrididae. Special thank to Elizabeth Grobbelaar for her linguistic improvements.

References

Aguilar G., Blanchon D., Foote H., Pollonais C., Mosee A., 2015.- Queensland fruit fly invasion of New Zealand: predicting area suitability under future climate change scenarios.- *Unitec ePress Perspectives in Biosecurity Research Series*, 2. [online] URL: http://www.unitec.ac.nz/epress

Araújo M. B., Pearson R. G., 2005.- Equilibrium of species' distributions with climate.- *Ecography*, 28: 693-695.

Araújo M. B., Alagador D., Cabeza M., Nogués-Bravo D., Thuiller W., 2011.- Climate change threatens European conservation areas.- *Ecology Letters*, 14: 484-492.

Baselga A., Araújo M. B., 2009.- Individualistic vs community modelling of species distributions under climate change.- *Ecography*, 32: 55-65.

Beck J., 2013.- Predicting climate change effects on agriculture from ecological niche modeling: who profits, who loses?- *Climate Change*, 116: 177-189.

Bellard C., Bertelsmeier C., Leadley P., Thuiller W., Courchamp F., 2012.- Impacts of climate change on the future of biodiversity.- *Ecology Letters*, 15: 365-377.

Berzitis E. A., Minigan J. N., Hallett R. H., Newman J. A., 2014.- Climate and host plant availability impact the future distribution of the bean leaf beetle (*Cerotoma trifurcata*).- *Global Change Biology*, 20: 2778-2792.

Biondi M., 1990.- Elenco commentato dei Crisomelidi Alticini della fauna italiana.- *Fragmenta Entomologica*, 22: 109-183.

Biondi M., 2017.- The endemic component in the Italian insect fauna: general aspects and conservation.- *Atti Accademia Nazionale Italiana di Entomologia*, 64: 35-41.

Biondi M., De Nardis G., 2001.- I Coleoptera Chrysomelidae del Massiccio del Gran Sasso d'Italia. Proposta per uno studio ecologico finalizzato al monitoraggio ambientale, pp. 36-54. In: *Monitoraggio biologico del Gran Sasso*, 2. (Cicolani B., Ed.).- Consorzio di Ricerca "Gran Sasso", Università degli Studi dell'Aquila, Dipartimento di Scienze Ambientali, Andromeda Editrice, Colledara, Italy.

Biondi M., Di Casoli M. T., 1996.- Il popolamento a Coleoptera Chrysomelidae del massiccio del Gran Sasso: analisi zoogeografica ed autoecologica (Insecta), pp. 176-198. In: *Monitoraggio biologico del Gran Sasso*, 1 (Cicolani B. Ed.) Consorzio di Ricerca "Gran Sasso", Università degli Studi dell'Aquila, Dipartimento di Scienze Ambientali, Andromeda Editrice, Colledara, Italy.

Biondi M., Urbani F., D'Alessandro P., 2013.- Endemism patterns in the Italian leaf beetle fauna (Coleoptera, Chrysomelidae).- *ZooKeys*, 332: 177-205.

Bisi F., Wauters L. A., Preatoni D. G., Martinoli A., 2015.- Interspecific competition mediated by climate change: which interaction between brown and mountain hare in the Alps?- *Mammalian Biology-Zeitschrift für Säugetierkunde*, 80: 424-430.

Bologna M. A., 1985.- Aspetti faunistici del Gran Sasso d'Italia. Caratteristiche del popolamento e ipotesi di gestione.- *Bollettino Club Alpino Italiano, sez. L'Aquila*, 11: 18-25.

Bologna M., Biondi M., Audisio P., Petrella A., 1992.- Studio di entomocenosi fitofaghe di pascoli primari e di derivazione della Majella (Abruzzo, Italia), pp. 90-102. In: *La fauna appenninica e la sua conservazione* (Inglisa M. Ed.), *Atti del I Convegno Nazionale "Paolo Barrasso"*, Caramanico Terme, Italy.

Bosso L., Rebelo H., Garonna A. P., Russo D., 2013.- Modelling geographic distribution and detecting conservation gaps in Italy for the threatened beetle *Rosalia alpina*.- *Journal for Nature Conservation*, 21: 72-80.

Brambilla M., Bergero V., Bassi E., Falco R., 2014.- Current and future effectiveness of Natura 2000 network in the central Alps for the conservation of mountain forest owl species in a warming climate.- *European Journal of Wildlife Research*, 61: 35-44.

Brunetti M., Lentini G., Maugeri M., Nanni T., Auer I., Böhm R., Schöener W., 2009.- Climate variability and change in the Greater Alpine Region over the last two centuries based on multi-variable analysis. *International Journal of Climatology*, 29: 2197-2225.

Carta A., 2014.- The impact of climate change on *Hypericum elodes* L. (Hypericaceae) distribution: predicting future trends and identifying priorities.- *Atti della Società Toscana di Scienze Naturali, Memorie*, 121: 15-24.

Ceccarelli S., Rabinovich J. E., 2015.- Global climate change effects on Venezuela's vulnerability to Chagas disease is linked to the geographic distribution of five Triatomine species.- *Journal of Medical Entomology*, 52: 1333-1343.

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

Chen F., Du Y., Niu S., Zhao J., 2015.- Modeling forest lightning fire occurrence in the Daxinganling Mountains of Northeastern China with MAXENT.- *Forests*, 6: 1422-1438.

Chłond D., Bugaj-Nawrocka A., Junkiert Ł., 2015.- Current and potential geographical distribution of *Platymeris biguttatus* (Linnaeus, 1767) with description of nymphs.- *Zoological Studies*, 54: 1-11.

Costantini E. A. C., Fantappié M., L'Abate G., 2013.- Climate and pedoclimate of Italy, pp. 354. In: *The Soils of Italy* (Costantini E. A. C., Dazzi C., Eds).- World Soils Book Series. Springer Science and Business Media, Dordrecht, The Netherlands.

Daccordi M., Ruffo S., 1976.- Le specie Appenniniche del genere *Oreina* (Coleoptera, Chrysomelidae).- *Bollettino del Museo Civico di Storia Naturale di Verona*, 3: 379-411.

D'Alessandro P., Biondi M., 2007.- Analisi zoogeografica della crisomelidofauna appenninica legata ai piani altitudinali montano, subalpino e alpino (Coleoptera, Chrysomelidae).- *Biogeographia*, 28: 461-494.

Devictor V., van Swaay C., Brereton T., Chamberlain D., Heliölä J., Herrando S., Julliard R., Kuussaari M., Lindstrom A., Reif J., Roy D. B., Schweiger O., Settele J., Stefanescu C., Van Strien A., Van Turnhoout C., Vermouzek Z., WallisDeVries M., Wynhoff I., Jiguet F., 2012.- Differences in the climatic debts of birds and butterflies at a continental scale.- *Nature Climate Change*, 2: 121-124.

Ehrlén J., Morris W. F., 2015.- Predicting changes in the distribution and abundance of species under environmental change.- *Ecology Letters*, 18: 303-314.

Elith J., Graham C. H., Anderson R. P., Dudík M., Ferrier S., Guisan A., Hijmans R. J., Huettmann F., Leathwick J. R., Lehmann A., Li J., Lohmann L. G., Loiselle B. A., Manion G., Moritz C., Nakamura M., Nakazawa Y., Overton J. McC., Peterson A. T., Phillips S. J., Richardson K. S., Scachetti-Pereira R., Schapire R. E., Soberón J., Williams S., Wisz M. S., Zimmermann N. E., 2006.- Novel methods improve prediction of species' distributions from occurrence data.- *Ecography*, 29: 129-151.

Escalante T., Linaje M., Illoldi-Rangel P., Rivas M., Estrada P., Neira F., Morrone J. J., 2009.- Ecological niche models and patterns of richness and endemism of the southern Andean genus *Eurymetopum* (Coleoptera, Cleridae).- *Revista Brasileira de Entomologia*, 53: 379-385.

FATTORINI S., 2010.- Biotope prioritisation in the Central Apennines (Italy): species rarity and cross-taxon congruence.- *Biodiversity and Conservation*, 19: 3413-3429.

FOGATO W., 1978.- Note sui *Luperus* bicolori italiani e descrizione di *L. leonardii* n. sp. (Coleoptera Chrysomelidae).- *Memorie della Società entomologica Italiana*, 57: 46-64.

FOURCADE Y., ENGLER J. O., RÖDDER D., SECONDI J., 2014.- Mapping species distributions with MAXENT using a geographically biased sample of presence data: a performance assessment of methods for correcting sampling bias.- *PLoS ONE*, 9 (5): e97122.

FREEMAN E. A., MOISEN G. G., 2008.- A comparison of the performance of threshold criteria for binary classification in terms of predicted prevalence and kappa.- *Ecological Modelling*, 217: 48-58.

GASTÓN A., GARCÍA-VIÑAS J. I., 2013.- Evaluating the predictive performance of stacked species distribution models applied to plant species selection in ecological restoration.- *Ecological Modelling*, 263: 103-108.

GRUEV B. A., 2000.- Southeuropean peninsular endemism of Alticinae (Coleoptera: Chrysomelidae).- *Travaux Scientifiques Universite de Plovdiv, Animalia*, 36: 35-50.

GUISAN A., THUILLER W., 2005.- Predicting species distribution: offering more than simple habitat models.- *Ecology Letters*, 8: 993-1009.

GUISAN A., TINGLEY R., BAUMGARTNER J. B., NAUJOKAITIS-LEWIS I., SUTCLIFFE P. R., TULLOCH A. I., REGAN T. J., BROTONS L., MCDONALD-MADDEN E., MANTYKA-PRINGLE C., MARTIN T. G., RHODES J. R., MAGGINI R., SETTERFIELD S. A., ELITH J., SCHWARTZ M. W., WINTLE B. A., BROENNIMANN O., AUSTIN M., FERRIER S., KEARNEY M. R., POSSINGHAM A. P., BUCKLEY Y. M., 2013.- Predicting species distributions for conservation decisions.- *Ecology Letters*, 16: 1424-1435.

HERNANDEZ P. A., GRAHAM C. H., MASTER L. L., ALBERT D. L., 2006.- The effect of sample size and species characteristics on performance of different species distribution modeling methods.- *Ecography*, 29: 773-785.

HIJMANS R. J., CAMERON S. E., PARRA J. L., JONES P. G., JARVIS A., 2005.- Very high resolution interpolated climate surfaces for global land areas.- *International Journal of Climatology*, 25: 1965-1978.

HU X. G., JIN Y., WANG X. R., MAO J. F., LI Y., 2015.- Predicting impacts of future climate change on the distribution of the widespread conifer *Platycladus orientalis*.- *PLoS ONE*, 10: e0132326.

IPCC, 2013.- Summary for Policymakers. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (STOCKER T. F., QIN D., PLATTNER G.-K., TIGNOR M., ALLEN S. K., BOSCHUNG J., NAUELS A., XIA Y., BEX V., MIDGLEY, P. M., Eds).- Cambridge University Press, Cambridge, UK.

IUCN, 2016.- *The IUCN red list of threatened species*. Version 2016-3. [online] URL: http://www.iucnredlist.org

KAMINO L. H. Y., SIQUEIRA M. F., SÁNCHEZ-TAPIA A., STEHMANN J. R., 2012.- Reassessment of the extinction risk of endemic species in the Neotropics: how can modelling tools help us.- *Natureza & Conservação*, 10: 191-198.

KUMAR S., STOHLGREN T. J., 2009.- Maxent modeling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia.- *Journal of Ecology and the Natural Environment*, 1 (4): 94-98.

LA GRECA M., 2002.- Vicende paleogeografiche e componenti della fauna italiana, pp. 448. *La fauna in Italia* (MINELLI A., CHEMINI C., ARGANO R., RUFFO S., Eds).- Touring Editore, Milano, Italy.

LEONARDI C., 1975.- Le *Psylliodes* appenniniche del Museo Civico di Storia Naturale di Verona (Coleoptera Chrysomelidae).- *Bollettino del Museo Civico di Storia Naturale di Verona*, 2: 51-90.

LEONARDI C., 2007.- Dati inediti sul genere *Psylliodes* Latreille, con descrizione di quattro nuove specie mediterranee (Coleoptera Chrysomelidae).- *Atti della Società italiana di Scienze naturali e del Museo civico di Storia naturale di Milano*, 148: 161-240.

LOBO J. M., JIMÉNEZ-VALVERDE A., REAL R., 2007.- AUC: a misleading measure of the performance of predictive distribution models.- *Global Ecology and Biogeography*, 17: 145-151.

MAGISTRETTI M., RUFFO S., 1961.- Considerazioni sulla diffusione nell'Italia appenninica di alcuni generi di coleotteri Carabidi e Crisomelidi.- *Atti dell'Accademia Nazionale Italiana di Entomologia*, 7: 137-179.

MASSA B., FONTANA P., BUZZETTI F. M., KLEUKERS R., ODÉ B., 2012.- *Orthoptera*. Fauna d'Italia 48.- Ed. Calderini, Bologna, Italy.

O'DONNELL M. S., IGNIZIO D. A., 2012.- Bioclimatic predictors for supporting ecological applications in the conterminous United States.- *U.S. Geological Survey Data Series*, 691: 10.

PARMESAN C., 2006.- Ecological and evolutionary responses to recent climate change.- *Annual Review of Ecology, Evolution, and Systematics*, 37: 637-669.

PARMESAN C., YOHE G., 2003.- A globally coherent fingerprint of climate change impacts across natural systems.- *Nature*, 421: 37-42.

PEARSON R. G., DAWSON T. P., 2003.- Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful?- *Global ecology and biogeography*, 12: 361-371.

PEARSON R. G., RAXWORTHY C. J., NAKAMURA M., TOWNSEND PETERSON A., 2007.- Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar.- *Journal of Biogeography*, 34: 102-117.

PEDROTTI F., GAFTA D., 2003.- The high mountain flora and vegetation of the Apennines and the Italian Alps.- *Ecology Studies*, 167: 73-84.

PHILLIPS S. J., DUDÍK M., 2008.- Modeling of species distributions with MaxEnt: new extensions and a comprehensive evaluation.- *Ecography*, 31: 161-175.

PHILLIPS S. J., ANDERSON R. P., SCHAPIRE R. E., 2006.- Maximum entropy modeling of species geographic distributions.- *Ecological Modelling*, 190: 231-259.

PIPER R. W., COMPTON S. G., 2010.- Population size and dispersal ability of *Cryptocephalus nitidulus* (Linnaeus, 1758) (Col.: Chrysomelidae).- *The Entomologist's record and Journal of variation*, 122: 257-264.

RAMIREZ-VILLEGAS J., CUESTA F., DEVENISH C., PERALVO M., JARVIS A., ARNILLAS C. A., 2014.- Using species distributions models for designing conservation strategies of Tropical Andean biodiversity under climate change.- *Journal for Nature Conservation*, 22: 391-404.

REBELO H., TARROSO P., JONES G., 2010.- Predicted impact of climate change on European bats in relation to their biogeographic patterns.- *Global Change Biology*, 16: 561-576.

REIF J., FLOUSEK J., 2012.- The role of species' ecological traits in climatically driven altitudinal range shifts of central European birds.- *Oikos*, 121: 1053-1060.

REMYA K., RAMACHANDRAN A., JAYAKUMAR S., 2015.- Predicting the current and future suitable habitat distribution of *Myristica dactyloides* Gaertn. using MaxEnt model in the Eastern Ghats, India.- *Ecological Engineering*, 82: 184-188.

RUFFO S., STOCH F., 2006.- Checklist and distribution of the Italian fauna.- *Memorie del Museo Civico di Storia Naturale di Verona, Sezione Scienze della Vita*, 17: 1-303.

STOCH F., 2006.- L'assetto zoogeografico dell'Appennino centro-settentrionale.- *Biogeographia*, 27: 129-150.

THOMAS C. D., CAMERON A., GREEN R. E., BAKKENES M., BEAUMONT L. J., COLLINGHAM Y. C., ERASMUS B. F. N., FERREIRA DE SIQUEIRA M., GRAINGER A., HANNAH L., HUGHES L., HUNTLEY B., VAN JAARSVELD A. S., MIDGLEY G. F., MILES F., ORTEGA-HUERTA M. A., PETERSON A. T., PHILLIPS O. L., WILLIAMS S. E., 2004.- Extinction risk from climate change.- *Nature*, 427: 145-148.

TRAVIS J. M. J., DELGARDO M., BOCEDI G., BAGUETTE M., BARTON K., BONTE D., BOULANGEAT I., HODGSON J. A., KUBISCH A., PENTERIANI V., SAASTAMOINEN M., STEVENS V. M., BULLOCH J. M., 2013.- Dispersal and species' responses to climate change.- *Oikos*, 122: 1532-1540.

URBANI F., D'ALESSANDRO P., FRASCA R., BIONDI M., 2015.- Maximum entropy modeling of geographic distributions of the flea beetle species endemic in Italy (Coleoptera: Chrysomelidae: Galerucinae: Alticini).- *Zoologischer Anzeiger*, 258: 99-109.

VAN DER PUTTEN W. H., MACEL M., VISSER M. E., 2010.- Predicting species distribution and abundance responses to climate change: why it is essential to include biotic interactions across trophic levels.- *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365: 2025-2034.

VAN GILS H., CONTI F., CIASCHETTI G., WESTINGA E., 2012.- Fine resolution distribution modelling of endemics in Majella National Park, Central Italy.- *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology*, 146: 276-287.

VAN VUUREN D. P., STEHFEST E., ELZEN M. G., KRAM T., VLIET J., DEETMAN S., ISAAC M., GOLDEWIJK K. K., HOF A., BELTRAN A. M., OOSTENRIJK R., VAN RUIJVEN B., 2011.- RCP2.6: exploring the possibility to keep global mean temperature increase below 2°C.- *Climatic Change*, 109: 95-116.

VOLDOIRE A., SANCHEZ-GOMEZ E., SALAS Y MÉLIA D., DECHARME B., CASSOU C., SÉNÉSI S., VALCKE S., BEA I., ALIAS A., CHEVALLIER M., DÉQUÉ M., DESHAYES J., DOUVILLE H., FERNANDEZ E., MADEC G., MAISONNAVE E., MOINE M.-P., PLANTON S., SAINT-MARTIN D., SZOPA S., TYTECA S., ALKAMA R., BELAMARI S., BRAUN A., COQUART L., CHAUVIN F., 2013.- The CNRM-CM5.1 global climate model: description and basic evaluation.- *Climate Dynamics*, 40: 2091-2121.

ZHU G., LIU G., BU W., LIS J. A., 2013.- Geographic distribution and niche divergence of two stinkbugs, *Parastrachia japonensis* and *Parastrachia nagaensis*.- *Journal of Insect Science*, 13: 1-16.

Authors' addresses: Maurizio BIONDI (corresponding author: maurizio.biondi@univaq.it), Fabrizia URBANI, Paola D'ALESSANDRO, Department of Health, Life and Environmental Sciences, University of L'Aquila, via Vetoio, 67100 Coppito-L'Aquila, Italy.

Received September 26, 2016. Accepted May 23, 2017.