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Updating distribution of *Borbo borbonica* (Boisduval, 1833) in southern Iberian Peninsula (Lepidoptera, Hesperiidae): potential and future distribution models

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Abstract. The Borbo Skipper (*Borbo borbonica*) (Lepidoptera, Hesperiidae) is one of the European butterflies with a more restricted geographical distribution. It has been observed in several localities of southern Spain next to the Strait of Gibraltar, in an area that includes the southernmost latitude of continental Europe. In this paper we update the current known distribution of the species by compiling bibliographic data and our field data, demonstrating the status of resident and current colonization of south-western Iberian Peninsula.
We model the potential distribution of this species with Maxent using both bioclimatic, topographic and land use variables obtaining a 99% success rate (AUC value). We also predict further expansion of this species in southern Spain in a climate change scenario for 2050. These models can be effective tools for monitoring and management in possible future actions for the conservation of the discussed species.

Key words: Distribution, Maxent, models, global change, *Borbo borbonica*, Lepidoptera, Hesperiidae, Iberian Peninsula.

Introduction

The genus *Borbo* Evans, 1949 includes about 20-22 species spread in the Ethiopic and Eastern region, including Australia and New Guinea (Corbet et al. 1992). In Europe, only *B. borbonica* is present, with a marginal and eccentric distribution in relation to other species of the genus (García-Barros et al. 2013).

B. borbonica is a Lepidoptera (Papilionoidea) belonging to the family Hesperiidae. This skipper was described from Madagascar as "*Hesperia borbonica*" Boisduval, 1833 (*Faune entomologique*, Madagascar). Later, the subspecies "*Hesperia borbonica zelleri*" Lederer, 1855 (*Verh Ges Wien zool.-bot*, 5: 194; type locality: Syria) and "*Pamphila borbonica holli*" Oberthür, 1910 (*Étud. Lép. comp.*, 4: 363; type locality: Algeria) were described. The two above mentioned taxa are currently considered as synonyms of the nominate subspecies by several authors, e.g. Tennent (1996). In this last interesting paper about the Lepidoptera of North Africa (especially Morocco) the taxon *B. borbonica* from Northern Africa is considered the same taxon existing in southern Spain, as the nominal subspecies. The taxon "*zelleri*" is considered in Tolman & Lewington (1997) as a subspecies, despite being the type locality (Syria) far away from the studied area of the southern Iberian Peninsula and surrounding areas (Morocco and Algeria), and the very similar morphology throughout its global range.

Whilst in Europe the occurrence of *B. borbonica* has only been confirmed in the south of the Iberian Peninsula, this Hesperiidae is widely present worldwide, a detail that is often overlooked in some references. It is distributed in a large number of African countries (Algeria, Botswana, Cape Verde, Egypt, Gambia, Ghana, Guinea, Ivory Coast, Kenya, Liberia, Madagascar, Seychelles, Mauritania, Rodriguez islands, Mauritius, Reunion, Morocco, Mozambique, Namibia, Nigeria, Senegal, Sierra Leone, South Africa, Swaziland, Togo, Zambia, Zimbabwe) as well as in the Middle East (Israel, Lebanon, Syria).

This powerful migratory skipper is the largest of the European Hesperiidae and has several established populations in the South of the Iberian Peninsula. In Spain, the species had been detected so far only in the province of Cadiz, in 9 UTM (10 km) squares (Moreno Duran 1991, Muñoz Sariot 2013, Cuvelier & Rowlings 2015) and in Malaga in 2 UTM squares (Moreno-Benítez 2013, Cuvelier & Rowlings 2015). Older records of Iberian Peninsula, in the eastern coast of Catalonia, can be considered as extinct according to Muñoz Sariot (2013) or attributable to *Gegenes nostrodamus* (Fabricius, 1793) (Garcia-Barros et al. 2013). New recent records further north, suggest large capacity of colonising new areas, for example mainland Spain and Portugal. According to Muñoz Sariot (2013), the life cycle of this species is trivoltine, being on the wing from May to October. Preimaginal stages have been described in detail by Martiré & Rochart (2008) and Muñoz Sariot (2013).

As most other species of skippers, its larvae feed on many species of grasses including cultivated ones: *Pennisetum, Panicum, Oryza, Zea* and *Ehrharta* (Larsen 1996) having therefore a large capacity of colonising new areas. In Morocco and Algeria larvae feed on *Sorghum halepense* (L.) Pers., and so does when breeding in captivity (Muñoz Sariot, 2013). This Poaceae colonises areas with certain soil moisture, growing frequently along ditches and irrigated crop edges (Romero 2009a, Romero Zarco 1987a). In southern Spain, *Polypogon viridis* (Gouan) Breistr., a perennial species of nitrified hydrophilic grassland, is the only known food plant (Muñoz Sariot 2013). It is a stoloniferous species that further displays rooting nodes. *P. viridis* is also common along ditches, irrigated crop edges and on river banks. Finally, *Panicum repens* L., other potential Iberian food plant, is also a perennial hydrophilic grass mainly growing on sandy substrates.

Habitats of *B. borbonica* are frequently disturbed and usually grazed areas, near waterways and grassland with large-sized grasses and abundant nectar sources. Butterflies were also detected in urban gardens with abundant nectar sources, such as in the city of Malaga, on the university campus (Moreno-Benitez 2013) or residential gardens near Cape Espartel in Tangier (Morocco, October 2012, *pers. obs.*).

On the other hand, the development of models to predict the distribution of many species is a valid tool for conservation planning and for studying the biology and distribution of species (Waldhardt et al. 2004, Kramer-Schadt et al. 2013). Species distribution modelling tools are becoming heavily popular in ecology and are being widely used in many ecological applications (Elith et al. 2006). Spatial modelling can provide an insight into the potential ranges of species for which data are limited (Engler et al. 2004). The species distribution models (SDM) are an ecological tool to meet the potential areas sensitive to host a particular species (Drake & Bossenbroek 2009, Merow et al. 2013) or even to predict what might be the future distribution due to the effects of climate change (Thuiller 2003, Parmesan 2006). Models are useful to find out the suitability of the territory for the studied species, and are especially useful for those species whose current distribution is not well known or is a reflection of sampled areas by researcher. Distribution models quantify the probability of species occurrence based on predictor variables, as climatic or topographic layers, and the known occurrence localities of the species (Estrada 2008). The model reliability and predictive value rely heavily on the accurate selection of those variables, that is to say, of the determinants of environmental variability in the area where the species is present. (Soria-Auza et al. 2010, Obregón et al. 2014).

Maxent (Phillips et al. 2006) uses presence-only data to predict the distribution based on the theory of maximum entropy. The software attempts to find a probability distribution of occurrence that is closest to uniform while still subject to environmental variables. The use of this software should maximize differences in ecological niche models allowing for a more comprehensive view of potential species distributions (Phillips et al. 2006).

Climate change is supposed to affect directly the distribution of species (Parmesan 2006). Thus, higher temperatures and changes in rainfall patterns may have an adverse effect on endangered species and those with very limited dispersal ability (Hoyle & James 2005, Khanum *et al*. 2013), although these predictions should be taken with caution (Merrow et al. 2013). Early detection, prediction, and long term monitoring are crucial to the effective management of invasive species and to minimize these effects (Kumer & Stohlgren 2009), although in the case of North African species it could be a great opportunity to colonise the southern countries of Europe.

In this paper we present the results of a study of the distribution of *B. borbonica*, a rare and migratory Hesperiidae that throughout Europe appears as resident only in Southern Spain. It is not considered as a threatened species in Europe, classified as Not Applicable (NA) in the UICN Red list (Van Swaay et al. 2010). The two main aims of our study were to update the current known distribution and to determine whether habitat modelling could be used to reveal the potential current and future distribution of this species in a global change scenario. Both kinds of information (current and future potential distribution) are important tools for the conservation of the species and its habitats, and to predict which of those habitats are more suitable for a future colonization.

Material and methods

Occurrence data and updating the current distribution

To develop the distribution maps we compile both bibliographic data (Moreno Duran 1991, Muñoz Sariot 2013, Moreno-Benitez 2013, Cuvelier & Rowlings 2015) and field observations of the authors, as well as other colleagues' records who have contributed with unpublished localities. Eldier records of NE Iberian Peninsula have not been taken into account, considered misidentifications with *G. nostradamus* by some authors (García-Barros et al. 2013). The maps were generated with ArcGIS 10.2 software (ESRI, Redlands, CA, USA) with a 10 x 10 km resolution, based on the compilation of the whole known information of distribution of this species in Europe.

Distribution models

Maxent software was used to determine the preference of *B. borbonica* for a particular habitat type, and to estimate the parameters that have effect on the species occurrence. The predictive distribution model was performed using the modelling software Maxent version 3.3.3 (Phillips et al. 2006). The species occurrence is the dependent variable and bioclimatic variables, elevation, slope, aspect and land use are the predictors. Maxent is maximum entropy based software that estimates the probability distribution for a species' occurrence based on environmental variables (Phillips et al. 2006). It requires only species presence data and environmental variables for a study area. Maxent generates an estimate probability of presence of the species that varies from 0 to 1, being 0 the lowest probability and 1 the highest one.

Figure 1. *Borbo borbonica* female adult nectaring in *Narcissus serotinus*, from one of the localities in the province of Sevilla. Author: Diego Conradi, date: October-25-2014.

Environmental variable layers

We considered fifteen environmental variables as potential predictors of the *B. borbonica* habitat distribution (Table 1). These variables were chosen based on their biological relevance to butterfly species distributions and other habitat modelling studies (Obregón et al. 2014, Fernández et al. 2015). The combination of the temperature and precipitation values produces biologically significant variables, which are known as bioclimatic variables. Five variables were chosen that were considered biologically more meaningful amongst nineteen bioclimatic variables to define ecological tolerances of *B. borbonica* in the current geographic range. These variables were obtained from WorldClim dataset (Hijmans et al. 2005) at 30 arc-second (approximately 1 km^2) resolution.

Topographic variables, such as elevation data (Digital Elevation Model; DEM) were also obtained from the WorldClim 50 m spatial resolution. The DEM data were used to generate slope and aspect (both in degrees) using Environmental Systems Research Institute's ArcGIS version 10.2, 'Surface Analysis tool' function (ESRI, Redlands, California, USA). The variables used for the potential distribution modelling are shown in Table 1.

Furthermore, to test the relationship between variables and to limit the effect of collinearity, the Spearman correlation statistic was applied, taking r ≥ 0.8 as thresh-

Table 1. Analysed environmental variables, source/references and units.

Environmental variable	Abbreviation	Source/Reference	Units
Annual Mean Temperature	Bio 1	Worldclim; Hijmans et al. 2005	ºC
Mean Temperature of Driest Quarter	Bio 9	Worldclim; Hijmans et al. 2005	ºC
Mean Temperature of Warmest Quarter	Bio 10	Worldclim; Hijmans et al. 2005	º C
Mean Temperature of Coldest Quarter	Bio 11	Worldclim; Hijmans et al. 2005	º C
Annual Precipitation	Bio 12	Worldclim; Hijmans et al. 2005	mm.
Precipitation of Warmest Quarter	Bio 18	Worldclim; Hijmans et al. 2005	mm.
Precipitation of Coldest Quarter	Bio 19	Worldclim; Hijmans et al. 2005	mm.
Elevation	ELE	Digital Elevation Model (DEM), Generated in GIS	m.
Slope	SLO	Digital Elevation Model (DEM), Generated in GIS	degree
Aspect	ASP	Digital Elevation Model (DEM), Generated in GIS	degree
Continuous urban fabric	CUF	CORINE Land Cover	%
Shrub	SHR	CORINE Land Cover	%
Permanently irrigated land	IRR	CORINE Land Cover	%
Rice fields	RIC	CORINE Land Cover	%
Sparsely vegetated areas	SVA	CORINE Land Cover	%
Water bodies and courses	WBC	CORINE Land Cover	%

old for those correlated variables (Elith et al. 2006).

For validating the distribution model and selected variables for the other models, the metric area under the ROC curve (AUC) was calculated (Fielding & Bell 1997). An test AUC of 0.5 is considered not to be better than random, while a value of 1 is the most explanatory model. In addition, the model was evaluated by calculating sensitivity, setting as threshold the ETSS (Equal training sensitivity and specificity) value (Fielding & Bell 1997). An AUC value higher to 0.8 is considered a good accuracy to model (Newbold et al. 2009).

Trying to answer the question of whether climate change may favour the spread of the species, a model under a future climate change scenario was performed. The IPCC (2014) mathematic model predictions of climate change in an A1B emission of CO_2 scenario, with a spatial resolution of 30 arc-second (1 km approx.), was used for the future model. With these new variables associated with grids, we built a predictive model in a future climate change scenario using the Maxent software. We followed the same methodology as in the current potential model.

Results

The unpublished localities we provide and their respective UTM squares are shown in Table 2. The occurrence UTM squares of the species in southern Peninsula combining bibliographic references and unpublished records data are updated, providing a total of 18 squares in Europe (Fig. 2), all of them included in Andalusia (southern Spain).

Ecology and behaviour

From our field observations of butterfly adults we can list a large number of species of nectar sources, especially observed between September and November, coinciding with the maximum sighting of individuals of this species.

In Southern Cadiz *B. borbonica* are often seen sucking up nectar from *Dittrichia viscosa* (L.) Greuter, *Lantana camara* L . and *Heliotropium europaeum* L. It has also been observed nectaring on the allochthonous naturalized Convolvulaceae species *Ipomoea indica* (Burm.) (David Barros, pers. comm.). In Seville, the imagos used as nectar sources *Narcissus serotinus* L., *Ajuga iva* subsp. *iva* (L.) Schreb., *Diplotaxis catholica* (L.) DC. and *H. europaeum*. In Huelva we have observed it on *Bidens aurea* (Aiton) Sherff and *L. camara*.

Distribution models

The potential distribution model (Fig. 3) shows the occurrence probability ranking for the Iberian Peninsula. The model was replicated 15 times by "cross validation" method. On the other hand, 8 occurrence records for training and 10 for testing have been used. The value of the test AUC (Area Under the Curve) was 0.996, higher than 0.8, according to the model value with high accuracy (Newbold et al. 2009). Equal training Sentitivity and Specificity threshold was 0.298.

The variable contributions to the model, in percent, are reflected in the following table (Table 3).

The Maxent model predicted potential suitable habitat for *B. borbonica* with high success rates (AUC= 0.996). The sensitivity value was 0.911 at threshold (ETTS) of 0.272, and was statistically significant (P = 0.0015, for threshold of 0.272). Therefore, the most suitable habitat for *B. borbonica* was accurately predicted in southern Europe.

Only bioclimatic variable future model (2050; A1B global change scenario) shows the progress of the species gaining habitat inland Iberian Peninsula, occupying much of the low Guadalquivir Valley, south-western Andalusia and in the Portuguese regions: Algarve, Alentejo, Ribatejo and Estremadura. In contrast, the predicted habitat loss is minimal, only in some coastal localities in central and eastern Andalusia (Fig. 4). The test AUC value is 0.989 (Sensitivity: 0.872), which, like the previous one, shows a high reliability. The model percent contributions of the variables used are provided in Table 4.

Discussion

As described in Muñoz Sariot (2013) *B. borbonica* is on the wing from May to October in three different generations, being the last one (September - October) the most abundant. This time of the year coincides in southern Spain with the dry season in which most of the annual plants, including grasses, are wilted. This scenery seems to be very important in explaining its distribution and possibilities of expansion. To be able to find nectar source plants and food plants for egg laying for continuous larval development (Muñoz Sariot 2013) during the dry season of the year, there are only two possibilities: to choose perennial grasses or to choose grasses growing in the scarce humid places that remain during the dry season in southern Spain: river banks, irrigation ditches, irrigated cultivations, etc. and, of course, a combina- tion of both possibilities, that is, perennial or cultivated grasses growing on humid places, where some plants can be also in full bloom. This fact

Table 2. *Borbo borbonica* unpublished localities in Europe, all of them in southern peninsular Spain.

Locality	Province	UTM (10 km)	Observed individuals	Date (month)	Year	Observer
Puerto Real	Cádiz	29SQA54	2	Sept.	2013-2014	P. Chapela & J.A. Chanivet
Pelayo	Cádiz	30STE79	3 (♀♂)	Sept.-Oct.	2013-2014	D. Barros
Castellar de la Frontera	Cádiz	30STF81	2♂1♀	October	2013	R. Obregón
Puebla del Rio	Sevilla	29SQB52	6♂2♀	Oct.-Nov.	2014	D. Conradi
Puebla del Rio	Sevilla	29SQB42	3♀	November	2014	R. Obregón
Isla Mayor	Sevilla	29SQB41	2♂	July & Oct.	2013-2014	R. Obregón
Isla Mayor	Sevilla	29SQB41	1♀	November	2014	R. Obregón
Hinojos	Huelva	29SQB32	1♀	July	2014	R. Obregón

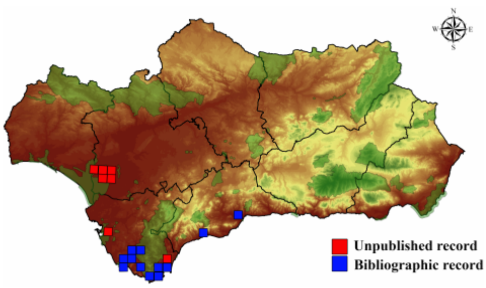

Figure 2. Real distribution map of *Borbo borbonica*, in Andalusia (Spain), currently the known distribution in Europe.

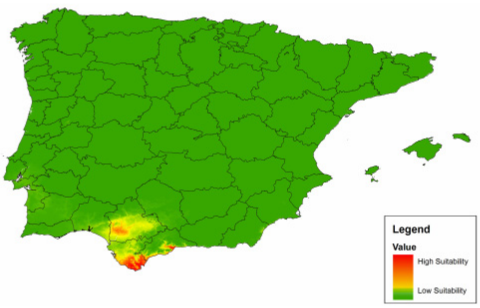

Figure 3. *Borbo borbonica* potential distribution model in Iberian Peninsula. From green to red colour: lowest-highest occurrence probability. 30 arc-second (approximately 1 km²) resolution.

implies that the distribution of *B. borbonica* should be necessarily very fragmented, as they have to colonise these very often distant patches, distributed in a matrix of very dry an inhospitable habitat. That is also the case of other butterflies living in the same area (Fernández Haeger et al. 2011).

Concerning food plants in its European distribution range, only Muñoz Sariot (2013) cites *Polypogon viridis*, in the field, and *Sorghum halepense* in

Table 3. Percent contribution of the analysed environmental variable layers.

Environmental variable	Percent contribution
Bio 11	52.0
Bio 19	12.9
Water bodies and courses	9.7
Irrigated permanently land	8.3
Bio 1	5.4
Bio 18	4.2
Bio 10	3.3
Shrub	1.3
Rice fields	1.1
Slope	0.6
Urban fabric continuous	0.4
Aspect	0.3
Elevation	0.3
Bio 12	0.1
Bio 9	0
Sparsely vegetated areas	0

captivity. We consider the possibility that *Panicum repens* can be used as food plant. The three Poaceae are perennial grasses, which seems to be essential for larval development during the summer. This three species, with hygrophilous and nitrophilous preferences, can frequently occur in the same habitats and are also very common in the irrigated crops and rice field edges in Guadalquivir Valley. The preference of *B. borbonica* for humid habitats, near permanent water courses seems to be the most important factor for colonising new areas and our new data suggest a recent expansion - colonisation phase. Very often the known habitats are disturbed and heavily grazed areas, where Ungulata herbivores concentrate during the summer. These features may help to understand the species distribution and possibilities of expansion.

In fact, when the environmental variables with higher percentage of contribution to the model are considered, both water bodies and courses and

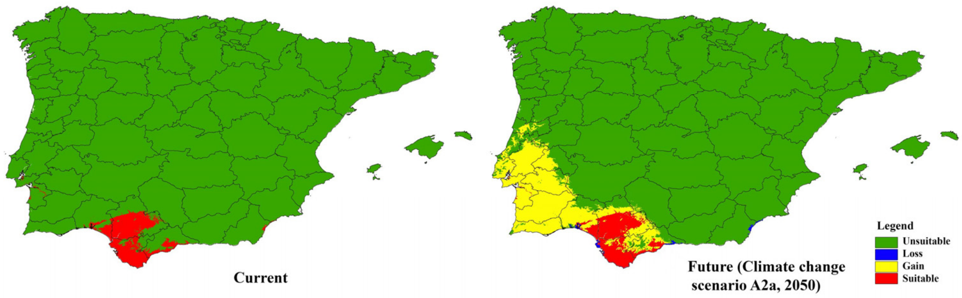

Figure 4. Predicted current (suitable and unsuitable) and future (suitable, lost, gained and unsuitable) habitat for *Borbo borbonica*. Current prediction are shown as a binarian map (red colour ≥ Equal Training Sentitivity and Specificity threshold= 0.298). Future predictions are based on an A1B emission scenario for 2050.

Table 4. Percent contribution to future model of selected bioclimatic variables.

Environmental variable	Percent contribution
Bio 11	53.2
Bio 19	12.2
Bio 1	0.1
Bio 18	33.2
Bio 10	0.6
Bio 12	0
Bio 9	0.8

irrigated crops are amongst the ones with the highest values, just after the average temperature of the coldest quarter and the precipitation of the same quarter. This can be interpreted as that species depends on a mild and humid winter, but also on the presence of humid places in the grids where they are present.

But the species could be wider distributed than we think. Some of the new localities detected in this paper are at an Euclidean distance of 170 km of the former localities where the species was first cited and they are in two opposite directions. Rice fields, irrigated crops and floodplains of the Guadalquivir Valley are suitable habitats that could be an important habitat for the species establishment in the future. The above mentioned food plants, can be found frequently along river courses, irrigation or drainage channels, ditches and edges. Thus, rivers and streams could serve as natural corridors for the expansion of this skipper across the bottoms of the valleys or coastal areas in which a milder winter could favour the expansion of this Hesperiidae in the Southern Iberian Peninsula.

Van Swaay et al. (2010) questioned *B. borbonica* as a resident species in the Iberian Peninsula, but data of Muñoz Sariot (2013) and our own data confirm that this species reproduces north to the Gibraltar strait. Notwithstanding, the Iberian populations may be occasionally reinforced by individuals migrating from the south, especially in late summer and early autumn. In fact the Gibraltar strait is only 15 km wide in its narrowest part, which is not an insurmountable barrier for butterflies. In resident Iberian populations, especially females disperse long distances searching of suitable habitats for reproduction. In addition to resident butterflies, a recruitment of individuals from North Africa could occasionally happen in the early autumn. This migratory and expansive-dispersive model could be very similar to *Colotis evagore* in southern Iberian Peninsula, with highly variable effective numbers and absences for years (Jordano et al. 1991). The maximum abundance in southern Spain could coincide with population peaks in the source patches in northern Africa. In this case, the Peninsula could be consider as a sink area for the species, or as a less-productive sites maintained by migrants (Kanda et al. 2009).

The potential distribution model, modelled with climatic, topography and land use and management variables shows a test AUC from the 15 iterations of 0.996, higher than the acceptable value: > 0.8 (Newbold et al. 2009). The Mean Temperature of Coldest Quarter is the largest contributing predictor at 52.0%, followed by Precipitation of Coldest Quarter (12.9%), Water bodies and courses (9.7%) and Irrigated permanently land (8.3%). They all add up to 82.9%. The rest of the variables are of minor importance. These contributions are expected in the case of a species with preference for habitats near permanent water courses and mild and humid winters. These locations have a common pattern: frosts are rare or non-existent and precipitation value is moderate for a Mediterranean climate.

The climate change is a current reality and the different forecast scenarios for the future does not seem very encouraging. Several international climate centres have developed these scenarios that can be used to model the distribution of numerous animal and plant species over this century (Flato et al. 2000). For restricted distribution and endemic species (especially mountain species) a significant reduction in its distribution is assumed (Gutiérrez Illán et al. 2010, 2012). In contrast, species with high colonising ability may be benefited in the near future, as is happening with many species of several insect groups (e.g. Odonata and Lepidoptera from northern Africa) (Jordano et al. 1991, Cano-Villegas & Conesa-García 2009) as the target species. According to IPCC (2014) the average temperature for European land area increased by 0.2 °C per ten year period, with a increasing estimate of 1.5-4.5°C at the end of the XXI century. The future distribution model of *B. borbonica* predicts that climate change may favour its expansion of this North African origin species in the Southern Iberian Peninsula. In order of importance the Bio 11 (53.2%), Bio 18 (33.2%) and Bio 19 (12.2%) are the largest contributing predictors (see Table 4).

The future model shows the predicted suitable habitats along the western Andalusia coastal areas and southern and south-western Portugal, coinciding with the wetlands and river courses. By contrast, predicted habitat loss is almost negligible.The exchange of individuals between coastal population patches, especially in autumn generation in which the number of individuals is higher, could usually occur. At the same time these localities might occasionally be reinforced by migrant individuals from northern Africa.

The models showed a potential change in the climatically suitable habitat and thus potential distribution of *B. borbonica* in southern Spain for 2050. This information may be valuable in planning future control efforts for migratory species from northern Africa. The alterations in climate and associated biotic interactions could allow the expansion of the species in next decades.

The wetlands with abundant nectar sources during all the year, especially in autumn (maximum effectives) are of vital importance for the establishment of the species. In these areas factors like overgrazing or trampling by ungulates should be of minor importance. But in irrigated crops areas (rice, corn, cotton, etc.) where pesticides are frequently used, *B. borbonica* might be suffering high rates of mortality. This is probably the most important factor that could affect the expansion in these kinds of habitats.

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References

Anderson, R.P., Lew, D., Peterson, A.T. (2003): Evaluating predictive models of species' distributions: criteria for selecting optimal models. Ecological Modelling 162(3): 211-232.

Boisduval, J.B. (1833): *Hesperia borbonica* Boisduval, 1833. Nouvelles Annales du Museum d'Histoire Naturelle 2: 213.

Cano-Villegas, F.J., Conesa-García, M.A. (2009): Expansión de *Trithemis kirbyi* Sélys, 1891 (Odonata: Libellulidae) en la provincia de Málaga (sur de la Península Ibérica). Boletín Sociedad Entomológica Aragonesa 44: 569–572.

Corbet, A.S., Pendlebury, H.M., Eliot, J.N. (1992): The butterflies of the Malay Peninsula. 4th revised edition by J.N. Eliot. Malayan Nature Society. Kuala Lumpur. 595 pp.

Cuvelier, S., Rowlings, M. (2015): Notes and recent observations concerning *Borbo borbonica* (Boisduval, 1833) (Lepidoptera: Hesperiidae) in Andalucía (Spain). Phegea 43(3) 64-69.

Drake, J.M., Bossenbroek J.M. (2009): Profiling ecosystem vulnerability to invasion by zebra mussels with support vector machines. Theoretical Ecology 2: 189-198.

Engler, R., Guisan, A., Rechsteiner, L. (2004): An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. Journal of Applied Ecology 41: 263–274.

Estrada, A. (2008): Evaluación de las redes de espacios naturales protegidos en Andalucía mediante el uso de modelos espaciales de distribución de vertebrados. Ecosistemas 17(3): 149-454.

Elith, J., Graham, H.C., 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., Nakazaw,a Y., Overton, J.McC., Townsend-Peterson, A., Phillips, S.J., Richardson, K., 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(2): 129-151.

Fernández, P., Jordano, D., Fernández Haeger, J. (2015): Living on the edge in species distribution models: the unexpected presence of three species of butterflies in a protected area in southern Spain. Ecological Modelling 312: 335-346.

Fernández Haeger, J., Jordano, D., León Melendez, M. (2011): Status and conservation of Asclepiadaceae and *Danaus* in southern Spain. Journal of Insect Conservation 15: 361–365.

Flato, G.M., Boer, G.J., Lee, W.G., Mcfarlane, N.A., Ramsden, D., Reader, M.C., Weaver, A.J. (2000): "The Canadian Centre for Climate Modeling and Analysis global coupled model and its climate". Climate Dynamics 16(6): 451–467.

Fielding, AH., Bell, J. (1997): A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24: 38-49.

García-Barros, E., Munguira, M.L., Martín-Cano, J., Romo-Benito, H., García-Pereira, P., Maravalhas, E.S. (2004): Atlas de las mariposas diurnas de la Península Ibérica e Islas Baleares.- Monografía de la Sociedad Entomológica Aragonesa 11: 1-228.

García-Barros, E., Munguira, M.L., Stefanescu, C., Vives Moreno, A. (2013): Lepidoptera Papilionoidea, In: Ramos M.A. et al. (eds.) Museo Nacional de Ciencias Naturales. CSIC. Madrid. Fauna Ibérica 37: 1-1213.

Gutiérrez Illán, J., Gutiérrez, D., Díez, S.B., Wilson R.J. (2012): Elevational trends in butterfly phenology: implications for species responses to climate change. Ecological Entomology 37: 134-144.

Gutiérrez Illán, J., Gutiérrez, D., Wilson, R.J. (2010): Fine-scale determinants of butterfly species richness and composition in a mountain region. Journal of Biogeography 37: 1706-1720.

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.

Hoyle, M., James, M. (2005): Global warming, human population pressure and availability of the world's smallest butterfly. Conservation Biology 19: 1113-1124.

Jordano, D., Retamosa, E.C., Fernandez Haeger J. (1991): Factors limitating the continental presence of *Colotis evagore* (Klug, 1829) in Southern Spain. Journal of Biogeography 18: 637-646.

Kanda, L.L., Fuller, T.K., Sievert, P.R., Kellogg, R.L. (2009): Seasonal source-sink dynamics at the edge of a species' range. Ecology 90(6): 1574-85.

Kramer-Schadt, S., Niedballa, J., Pilgrim, J. D., Schröder. B., Lindenborn, J., Reinfelder, V., Stillfried, M., Heckmann, I., Scharf, A.K., Augeri, D.M., Cheyne, S.M., Hearn, A.J., Ross, J., Macdonald, D.W., Mathai, J., Eaton, J., Marshall, A.J., Semiadi, G., Rustam, R., Bernard, H., Alfred, R., Samejima, H., Duckworth, J.W., Breitenmoser-Wuersten, Ch., Belant, J.L., Hofer, H., Wilting, A. (2013): The importante of correcting for sampling bias in MaxEnt species distribution models. Diversity and Distributions 19 (11): 1366-1379.

IPCC (2014): Climate Change 2014. Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri, R.K., Meyer, L.A. (eds.). IPCC, Geneva, Switzerland, 151pp.

Larsen, T.B. (1996): Butterflies as indicator species in Africa. Tropical Lepidoptera News 3(1): 3-4.

Khanum, R., Mumtaz, A.S., Kumar, S. (2013): Predicting impacts of climate change on medicinal asclepiads of Pakistan using Maxent modeling. Acta Oecologica 49: 23-31.

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 Natural Environment 1(4): 094-098.

Martiré, D., Rochat, J. (2008): Les Papillons de La Réunion et leurs chenilles. Biotope, Mèze (Collection Parthénope), Muséum national d'Histoire naturelle, Paris, 496 pp.

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

Moreno-Benítez, J.M. (2013): Primera cita de *Borbo borbonica zelleri* (Lederer, 1855) en Málaga (S de España) (Lepidoptera Hesperiidae). Arquivos Entomológicos 9: 133-134.

Moreno Duran, M.D. (1991): Mariposas diurnas a proteger en Andalucía. Junta de Andalucía, Consejería de Cultura y Medio Ambiente, Junta de Andalucía. 127pp.

Muñoz Sariot, M.G. (2013): Ciclo biológico, morfología de los estadios preimaginales y nuevos datos sobre la distribución de *Borbo borbonica zelleri* (Lederer, 1855) (Lepidoptera: Hesperiidae) en la provincia de Cádiz, España. Revista gaditana de Entomología IV(1): 137- 158

Newbold, T., Gilbert, F., Zalat, S., El-Gabbas, A., Reader, T. (2009): Climate-based models of spatial patterns of richness in Egypt's butterfly and mammal fauna. Journal of Biogeography 36: 2085-2095.

Obregón, R., Arenas-Castro, S., Gil-T., F., Jordano, D., Fernández-Haeger, J. (2014): Biología, ecología y modelo de distribución de las especies del género *Pseudophilotes* Beuret, 1958 en Andalucía (Sur de España) (Lepidoptera: Lycaenidae). SHILAP Revista de Lepidopterología 42(168): 501-515.

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

Phillips, S.J., Anderson, R.P., Schapired, R.E. (2006): Maximum entropy modelling of species geographic distributions. Ecological Modelling 190: 231-259.

Romero, A.T. (2009a): *Sorghum* Moench. pp.395-396. In: Blanca, G., Cabezudo, B., Cueto, M., Fernández López C., Morales Torres C. (eds.), Flora Vascular de Andalucía Oriental 1. Consejería de Medio Ambiente, Junta de Andalucía, Sevilla.

Romero, A.T. (2009b): *Polypogon* Desf. pp.353-354. In: Blanca, G., Cabezudo, B., Cueto, M., Fernández López C., Morales Torres C. (eds.), Flora Vascular de Andalucía Oriental 1. Consejería de Medio Ambiente, Junta de Andalucía, Sevilla.

Romero Zarco, C. (1987a): *Sorghum* Moench. pp.410-411. In: Valdés, B., Talavera, S., Fernández-Galiano, E. (eds), Flora Vascular de Andalucía Occidental 3. Editorial Ketres, Barcelona.

Romero Zarco, C. (1987b): *Polypogon* Desf. pp.441-443. In: Valdés, B., Talavera, S., Fernández-Galiano, E. (eds), Flora Vascular de Andalucía Occidental 3. Editorial Ketres, Barcelona.

Romo, H., Sanabria, P., García-Barros, E. (2013): Predicción de los impactos de cambio climático en la distribución sobre las especies de Lepidoptera. El caso del género *Boloria* Moore, 1900 en la Península Ibérica (Lepidoptera: Nymphalidae). SHILAP Revista de lepidopterología 41(162): 267-286.

Soria-Auza, R.W., Kessler, M., Bach, K., Barajas-Barbosa, P.M., Lehnert, M., Herzog, S.K., Böhner, J. (2010): Impact of the quality of climate models for modeling species occurrences in countries with poor climatic documentation: a case study from Bolivia. Ecological Modelling 221: 1221-1229.

Tennent, J. (1996): The buterflies of Marocco, Algeria and Tunisia. Print. Swindon Press Ltd, Swindon, Wiltshire, England. 217 pp.

Thuiller, W. (2003): Biomod-optimizing predictions of species distributions and projecting potential future shifts under global change. Global Change Biology 9: 1353-1362.

Tolman, T., Lewington, R. (1997): Butterflies of Britain & Europe: 320 pp. Harper Collins, London.

Waldhardt, R., Simmering, D., Otte, A. (2004): Estimation and prediction of plant species richness in a mosaic landscape. Landscape Ecology 19: 211-226.