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ORIGINAL PAPER

On the Iberian endemism *Eurylophella iberica* Keffermüller and Da Terra 1978 (Ephemeroptera, Ephemerellidae): current and future potential distributions, and assessment of the effectiveness of the Natura 2000 network on its protection

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Abstract

Eurylophella iberica Keffermüller and Da Terra, 1978 is an endemic insect species of the Iberian Peninsula whose distribution has been poorly studied to date with rather old and scattered records. Here we compiled all existing distribution records and add new records from recent sampling activities. We also used this updated distributional information and environmental data (climate and geology) to estimate both current and future potential distributions in different climate change scenarios. We found that currently ca. 50% of the total Iberian region could present suitable environmental conditions for *E. iberica* (all the Iberian Peninsula, save the most eastern and Mediterranean areas). However, the potential distributions estimated when considering future climate change scenarios showed a marked reduction in the areas with suitable environmental conditions for the species, especially in the south. The northwest part of the Iberian Peninsula is a crucial zone for the future survival of this endemic species. We also found that most populations that occur in areas with suitable (both current and future) environmental conditions fall outside the Natura 2000 network of protected areas. Our results represent the first attempt to estimate the potential distribution of this endemic species providing important insights for its conservation.

Keywords Aquatic insects · Potential distribution · Climate change · Endemic species · Rivers

Introduction

Eurylophella is a Holarctic genus that belongs to the family Ephemerellidae (Insecta: Ephemeroptera), and is distributed mainly in the Nearctic region (Funk and Sweeney 1994;

Bauernfeind and Soldán 2012). Only three valid species are distributed in the Palearctic region: *Eurylophella karelica* Tiensuu, 1935, *Eurylophella korneyevi* Martynov, Palatov and Godunko, 2015 and *Eurylophella iberica* Keffermüller and Da Terra, 1978 (Martynov et al. 2015). While the first two species are recorded from Eastern Europe and Transcaucasia, the latter is an endemic species of the Iberian Peninsula (Pardo et al. 1991; Alba-Tercedor and Jáimez-Cuéllar 2003). *Eurylophella iberica* larvae seem to prefer rivers and streams with lentic characteristics (Pardo et al. 1991), marginal zones, and even systems associated with lakes (Martínez-Sanz et al. 2012).

However, knowledge on the detailed distribution of *E. iberica* is scarce, with just few records scattered in the literature, and most before 1991 (Pardo et al. 1991). The species is currently known mostly from northern regions of Portugal and Spain, with some records located in central-south Spain (Castilla-León or Andalusia regions) detected in the 1980s and the early 1990s (e.g., Gonzalez del Tánago and De Jalón 1983; Gonzalez del Tánago 1984; Puig et al.

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1986; Vidal and Membiela 1994; García Rojas and Ferreras Romero 1995). This problem, denominated as the Wallacean shortfall (Lomolino 2004), is common for many species, especially for insects, whose geographical distributions are poorly understood and present many gaps. This lack of information limits distributional data being used in ecological, evolutionary and conservation research (Hortal et al. 2015).

Thus, as information on the distribution of *E. iberica* is currently spread in publications, reports and unpublished databases, our first objective is to update the known distribution of this endemic species, including unpublished data from our own sampling. Having updated the current distribution, we aim to estimate the current and future potential distributions of *E. iberica* in the Iberian Peninsula by means of species distribution modelling and considering different climate change scenarios. Finally, we seek to determine whether suitable condition for *E. iberica* falls within protected areas of the European Natura 2000 network. All this information could be useful for locating (i) future sampling efforts to detect areas where the species has been undetected to date; (ii) potentially threatened populations to which conservation management policies may be applied. This research will bring relevant information on this endemic species and represents a first attempt to evaluate its conservation status.

Materials and methods

Biological data

We compiled all the available distributional data of *E. iberica* from the scientific literature (scientific articles, technical reports, online databases including the Global Biodiversity Information Facility (GBIF 2017), PhD theses or unpublished records) All this was coupled with recent sampling campaigns performed by the authors in south Spain (2016–2017) (Table 1). This included records over the last 50 years (1968–2017). A few records with taxonomic uncertainties or with doubtful or imprecise localities were not considered in the study.

Current potential distribution

Climatically suitable areas were investigated by considering the climatic variables obtained from WORLDCLIM, version 1.3 (Hijmans et al. 2005). WORLDCLIM contains the climate data obtained from interpolating climate station records from 1950 to 2000.

A multidimensional envelope procedure (MDE, see Sánchez-Fernández et al. 2011 for the conceptual basis of this approach) was used to obtain a map with the potential distribution of *E. iberica*. Assuming that presence localities

reflect a subset of the suitable conditions under which a species can maintain viable populations, MDE is an approach directed at maximizing the capacity to represent geographically the potential distribution of species when they are only based on distributional data (see Jiménez-Valverde et al. 2011; Sánchez-Fernández et al. 2011). Firstly, and because MDE procedures strongly depend on the number of selected predictors (Beaumont et al. 2005), the climatic variables considered relevant for species distribution were estimated. The minimum set of climatic variables needed to explain the occurrence of *E. iberica* was calculated using an ecological-niche factor analysis (ENFA) in the Biomapper package (Hirzel et al. 2002). This procedure computes uncorrelated factors that can explain both species marginality (the distance between the species optimum and the average climatic conditions in the study area) and specialisation (the ratio of the ecological variance in the climate of the study area to that associated with the focal species). Factors were retained or ruled out based on their eigenvalues in relation to a broken-stick distribution (Hirzel et al. 2002). Then the maximum and minimum scores (extreme values) for all these relevant climatic variables were calculated in all the cells where presence of the species was observed after selecting all the grid squares with climatic values that fell within that range as suitable. In this way, the extreme values were used to derive a binary distributional hypothesis about the areas with climatically suitable conditions (climatic potential distribution) according to the assumption that recorded occurrences reflect the spectrum of the climatic conditions in which the species can survive and reproduce.

To obtain a continuous environmental suitability value on the potential distribution map, Mahalanobis distances (a multidimensional non-Euclidean distance measure) were calculated from each cell to the mean hypervolume of the selected variables, which refers to the species' presence records. This procedure has been widely used in spatial animal ecology (e.g. Etherington et al. 2009) and is considered an useful tool to estimate the environmental suitability area for a given species (Calenge et al. 2008; Sánchez-Fernández et al. 2013; Guareschi et al. 2013). Thus the final representation of the potential distribution for *E. iberica* was a map with continuous favourability values within its potential distribution, which ranged from 0 (low suitability) to 100 (high suitability).

However, the lithological composition of the substratum influences the conductivity and pH of aquatic systems and may affect the distribution patterns of aquatic species (e.g., Bonada et al. 2005; Neff and Jackson 2011). Therefore, the percentage of each grid cell with an acidic surface geology (i.e. both acidic bedrock and/or surface deposits), was also considered and included in the models. These data were obtained from the Geological Map of Spain (*Instituto Geológico y Minero de España IGME*). We removed all

Table 1 Compiled records of *Eurylophellaiberica* throughout the Iberian Peninsula (39 records)

State	Sites	References	Year	MGRS 10×10	%N2000
Portugal	Rio Sanguinhedo	Keffermuller and Da Terra (1978)	1975	29TNF47	0.0
	Rio Ave	Keffermuller and Da Terra (1978)	1975	29TNG70	0.0
	Ribeira de Figueira	Keffermuller and Da Terra (1978)	1975	29SPD17	46.9
	Rio Coura	Keffermuller and Da Terra (1978)	1975	29TNG34	18.1
	Rio Neiva	Keffermuller and Da Terra (1978)	1975	29TNG30	0.0
	Rio Homem	Keffermuller and Da Terra (1978)	1975	29TNG51	14.3
	Rio Pele	Keffermuller and Da Terra (1978)	1975	29TNF48	0.0
	Ribeiro da Aldeia	Keffermuller and Da Terra (1978)	1975	29TNF37	0.0
	Rio Coa	Keffermuller and Da Terra (1978)	1975	29TPE66	64.4
	Rio Vizela, Golaes	Alba-Tercedor (1981)	1968	29TNF69	0.0
	Rio Coura, Santa	Studemann and Tomka (1987)	1986	29TNG34	18.1
	Rio Olo	Sampaio et al. (2001)	1998	29TNF87	38.9
Spain	Zapateira, Louro River	Pardo et al. (1991)	1986	29TNG37	0.1
	Mos, Louro River	Pardo et al. (1991)	1986	29TNG37	0.1
	Porriño, Louro River	Pardo et al. (1991)	1986	29TNG36	4.4
	Eidos, Louro River	Pardo et al. (1991)	1986	29TNG36	4.4
	Cerquido, Louro River	Pardo et al. (1991)	1986	29TNG36	4.4
	Tuy, Louro River	Pardo et al. (1991)	1986	29TNG35	13.0
	Arrayal, Louro River	Pardo et al. (1991)	1986	29TNG35	13.0
	Ribadelouro_San Simón stream	Pardo et al. (1991)	1986	29TNG26	0.9
	Centears, Centears stream	Pardo et al. (1991)	1986	29TNG26	0.9
	Cerquido, Beceira stream	Pardo et al. (1991)	1986	29TNG36	4.4
	Pontellas, Laxas stream	Pardo et al. (1991)	1986	29TNG36	4.4
	Rebordans, Deikas stream	Pardo et al. (1991)	1986	29TNG35	13.0
	Rebordans, Rebordans stream	Pardo et al. (1991)	1986	29TNG25	14.0
	Invernadeiro, Puxo de Mogos stream	Pardo et al. (1991)	1986	29TPG36	57.3
	Porriño, Louro River	Biodiversidad Virtual (J. Lizón personal comm.)	2016	29TNG36	4.4
a	Lloredal stream (Esva Basin)	Puig et al. sampling	1992	29TQJ02	15.4
	Tera river, Trefacio	Gonzalez del Tánago and De Jalón (1983)	1982	29TPG96	26.3
	Tietar river, Piedralaves	Gonzalez del Tánago (1984)	1983	30TUK56	100
	Stream in Castrocontrigo	Vidal and Membiela (1994)	1991	29TQG36	0.1
	Yeguas River, Fuencaliente	García Rojas and Ferreras Romero (1985)	1984	30SUH84	78.6
a	Robledillo River	Mellado and Guareschi sampling	2016	30SVH05	100
a	Garganta del Prior (Sierra de La Palma)	Puig et al. sampling	2000	30STF70	38.3
a	Canuto del Puerto Oscuro (Sierra de Aljibe)	Puig et al. sampling	1999	30STF64	99.9
	Cañaveroso River	Márquez-Rodríguez (2015)	2010	29SQB36	92.3
	Rivera Huelva	Boyero (Personal Communciation)	2012	29SQC00	100
a	Rivera Huelva	Mellado and Guareschi sampling	2016–2017	29SQC00	100
a	Guadalbarbo River	Mellado and Guareschi sampling	2016–2017	30SUH32	18.4

year sampling years, %N2000 percentage of overlap between the 10×10 km cell and the Natura 2000 network, MGRS 10×10 code of the 10×10 km cell

^aNew records (first-time published, red points in Fig. S1)

the areas (10×10 km²) from the potential climatic distribution map that contained a lower acid surface geology percentage than the lowest percentage at which the species had been detected. We thus obtained a final binary

potential distribution map that showed the climatic and geologically suitable areas for *E. iberica*.

Future potential distribution

The climatic variable values found as being relevant for *E. iberica* were projected in relation to two future climate scenarios to estimate the potential range dynamics of this endemic species in the future.

The bioclimatic predictors for future scenarios (year 2080) were obtained from the CCCMA-CGCM2 climate model (Flato et al. 2000) through the CIAT database (<http://www.ccafs-climate.org>, Ramirez and Jarvis 2008). The A2 and B2 scenarios from the 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC 2007) were used. The A2 scenario is considered a more 'extreme' scenario, with a projected warming of a mean annual temperature of 3.8 ± 1.1 °C. On the contrary, B2 reflects a 'moderate' scenario, with an increase in the projected mean annual temperature (in the Iberian Peninsula) of 2.5 ± 1.0 °C ($\pm$ standard deviation). The projected changes in aquatic habitats according to climate change are based on the fact that land-based variables might be representative of the climatic conditions found in inland waters since river temperatures can be strongly influenced by air temperatures (Webb et al. 2003; Caissie et al. 2006; Alba-Tercedor et al. 2017), especially in middle reaches (Vannote et al. 1980). We also refined these maps by incorporating lithological information and by using the same procedure as explained above.

Overlapping the current distribution with protected areas

We focused here on the Natura 2000 network (hereafter N2000) in the Iberian Peninsula. N2000 represents a key tool for biodiversity conservation on the European scale and aims to guarantee the long-term survival of Europe's most valuable and threatened species and habitats. Four GIS data layers (Special Protection Areas and Special Areas of Conservation for Spain and Portugal), supplied by national conservation agencies, were processed and combined to produce a single layer of the current N2000 in the Iberian Peninsula. Then the overlapping proportions between each square (10×10 km) with records of *E. iberica* and N2000 were calculated. Subsequently, three types of squares were defined according to the calculated overlapping values: the squares represented within N2000 (overlapping value $\geq 50\%$), the marginally represented squares (from 1 to 50%) and the squares "outside" N2000 ($< 1\%$).

Results

The collected dataset contained 39 records (species/date/locality) located in $28 10 \times 10$ km² throughout the Iberian Peninsula (33 obtained from the bibliography and 6 new records from unpublished material and recent sampling; see Table 1 and Electronic supplementary material S1). All these records are located mostly in the western section of the Iberian Peninsula, and represent the most complete and updated distribution of *E. iberica*.

The most relevant climatic variables identified by ENFA, which were therefore used in the MDE procedure, were: mean temperature of warmest quarter (BIO10), precipitation of wettest quarter (BIO16) and precipitation of coldest quarter (BIO19).

The MDE results show that almost 75% of the total Iberian Peninsula may include suitable current climatic conditions for *E. iberica* (see Fig. 1a), mainly areas with mild summers and humid winter and autumn seasons. These areas represent the potential climatic distribution of *E. iberica* and are located throughout the Iberian Peninsula, except for the more strictly Mediterranean or semiarid areas. The potential distribution, estimated by considering future climate change scenarios, showed how the areas with suitable climatic conditions for the species had markedly been reduced (Fig. 1b–c). In both scenarios (A2 and B2), southern populations will almost completely enclose unsuitable conditions for the species to remain in these areas. Moreover, according to the more pessimistic scenario (A2), even the large Portuguese area with current good suitability would be drastically constrained, and northern Spain (mainly Galicia) would be the most important relict area for *E. iberica* in the future (Fig. 1c).

Within this climatic potential distribution, the areas with the best climatic suitability were mainly located in Portuguese territory, with other scattered areas in northern Spain with a clear Atlantic influence, and in the middle mountainous regions of central-south Spain (see Fig. 2a).

We found that the lowest percentage of acid surface (both rocks and deposits) in a square that recorded the presence of the studied species was 14%. Thus we removed all the areas (squares) that presented a lower percentage of acid surfaces than this value. The current potential distribution covered around 50% of the Iberian Peninsula surface (Fig. 1d–f). In this context the most environmentally suitable areas were mainly located in Portuguese territory coupled with Galicia Region and few other central-south Spain zones (see Fig. 2b). As in the future climate change scenarios (Fig. 1e–f), these environmentally suitable areas would undergo drastic reductions, and the north-western part of the peninsula would be the only area available for the species.

Fig. 1 Potential climatic distribution (**a** current climatic potential distribution; **b** B2 future scenario; **c** A2 future scenario). Environmental potential distribution (potential climatic distribution refined by geol-

ogy **d** current environmental potential distribution; **e** B2 future scenario; **f** A2 future scenario)

Fig. 2 **a** Map of the current potential distribution of *Eurylophella iberica* in the Iberian Peninsula showing climatic favourability from a dark colour (high suitability) to a light colour (low suitability). **b** Iberian Peninsula's current potential distribution of *Eurylophella iberica*

showing environmental favourability (climatic + geology) from a dark colour (high suitability) to a light colour (low suitability). These values were calculated by applying Mahalanobis distances (see the "Materials and methods" section)

Finally, after overlapping the 28 squares (10×10 km) in which *E. iberica* was recorded within N2000, we found that 8 squares (29%) were included to some extent in N2000 protected areas (an overlapping value $\geq 50\%$, see Fig. 3), with four squares overlapping more than 99%. The remaining 20 squares were marginally represented (11, 39%) or were outside N2000 (9, 32%). Overall the mean percentage of protected surface area for the 28 squares was 33.6% (see Table 1; Figs. 3 and S1), with values around 17% in Portugal and 45% in Spain.

Discussion

The present work updates the current distribution of *Eurylophella iberica* with the inclusion of unpublished records, which extends its current range size in some areas of central and south Spain. This effort allowed us to collect practically all the available information (as far as we know) about this endemic Ephemeroptera. Besides, the results obtained and displayed in Figs. 1, 2 and 3 provide

Fig. 3 Overlap among the localities with records of *Eurylophella iberica* and the Natura 2000 network (soft grey): white = overlap < 1%; grey 1–50%; black > 50%

useful information to be consulted by freshwater ecologists, taxonomists or biogeographers, and especially by conservation biologists. Furthermore, the environmental suitability maps provided herein represent the first attempt to estimate the potential distribution of *E. iberica* throughout the Iberian Peninsula, also evaluating the effects of different climate change scenarios.

Considering that aquatic biomonitoring activities are probably the most common way to obtain data on aquatic insect distribution, and that these activities are conducted mostly at the family level, it is likely that *E. iberica* had been overlooked in other freshwater systems. However, *Eurylophella* larvae can be easily recognised from other Ephemerellidae for their specific gills, particularly the filamentous pair on the first abdominal segment (details in Gonzalez del Tánago and De Jalón 1983; Martynov et al. 2015). The wide potential distribution obtained for *E. iberica* (almost 50% of the whole Iberian Peninsula) means that this species can appear in a relatively wide range of environmental conditions. However, it should be noted that the localities predicted as belonging to this potential distribution may be inhabited or not. Thus, potential distribution maps can be a useful tool to locate further sampling efforts in suitable areas to complete the current distribution and also to reduce uncertainty in geographically or taxonomically questionable records. We recommend prioritising future sampling efforts practically all over the Portuguese territory, as well as in areas of north Spain and parts of central-south Spain (e.g., the Castilla-La Mancha Region). A major sampling effort is also recommended in regions with old species records (e.g. 1980s–1990s), especially those located in areas with low environmental favourability. Once new records have been confirmed, they

can be incorporated into the model and maps to refine estimates of the potential distribution of *E. iberica*.

Climate change can have particularly strong impacts on ectotherm species (highly sensitive to temperature changes) such as aquatic insects like Ephemeroptera or Plecoptera, with short aerial stages and poor dispersal capability (Fenoglio et al. 2016). In our case, a notable shift towards the northern latitude of the Iberian Peninsula is expected, with dramatic consequences for southern populations (most of them unknown before this study). These trends are concordant with the shift of species' ranges towards higher latitudes and/or altitudes following their thermal preferences, which represents one of the most expected and already observed ecological impacts of climatic change worldwide (Parmesan and Yohe 2003). In fact, changes in distribution patterns have recently been estimated for aquatic macroinvertebrate families along Mediterranean Spain under global change scenarios (Alba-Tercedor et al. 2017). An analogous alert, specific for the Ephemeroptera fauna, has already been stressed by Conti et al. (2013), who highlighted that the Iberian Peninsula is among the most vulnerable areas to climate change in Europe. Similarly, 85% of the endemic macroinvertebrate species in the Iberian-Macaronesian region have been identified as climate-change “losers” (Domisch et al. 2013) in the same climate warming scenarios considered in this study.

Finally, the importance of taking into account invertebrates in conservation planning should be stressed, especially those that inhabit threatened freshwater ecosystems (e.g., lower and middle reaches of rivers, Sánchez-Fernández et al. 2008) which are globally, and on the Iberian Peninsula, less protected than other habitats (e.g., Joppa and Pfaff 2009; Guareschi et al. 2015). Our results also emphasise the value of incorporating climate change information and species' future potential distributions into the designs of conservation programmes and priorities (e.g. Cheng and Bonebrake 2017). Moreover, few conservation planning studies have focused on insects, as compared to other taxa (Wilson and Maclean 2011; Sánchez-Fernández et al. 2013). Some studies have already stressed the lack of effectiveness of the European Natura 2000 reserve network in representing the invertebrate fauna in different countries (e.g. Sánchez-Fernández et al. 2008; D'Amen et al. 2013). With *Eurylophella iberica*, the existing Natura 2000 network fails to represent the northern populations of this endemic species, especially in Portugal, where the percentage of overlap with N2000 is extremely low. Furthermore, this is particularly relevant if we consider that the future potential distributions of the species concentrate mostly in this area (the northern Iberian Peninsula), making it a critical zone for the future survival of this species. Thus based on our study results, we recommend taking effective conservation measures in these areas (e.g., specific sampling activities and research,

expansion of reserves, catchment-based conservation planning) to prevent the effects of climate change on this interesting species.

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Compliance with ethical standards

Conflict of interest No potential conflict of interest is reported by the authors.

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