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THE IMPACT OF CLIMATE CHANGE ON *HYPERICUM ELODES* L. (HYPERICACEAE) DISTRIBUTION: PREDICTING FUTURE TRENDS AND IDENTIFYING PRIORITIES

Abstract - *The Impact of Climate Change on* Hypericum elodes *L. (Hypericaceae) distribution: Predicting Future Trends and Identifying Priorities.* In this study the present and future predicted distribution of the Atlantic-European soft-water pools specialist *Hypericum elodes* L. (Hypericaceae) is modelled in order to facilitate appropriate decision making for conservation, monitoring and future research. Using the methods of Maximum Entropy the future distribution has been examined with the HadCM3 climate model over the year 2050.
H. elodes is confirmed as a climate-sensitive species, with a W-European distribution and preferences for acid substrates. The model shows a marked negative influence of climate change on *H. elodes*. In a locality analysis the outcome is a c. 58% reduction in the number of pre-existing bioclimatically suitable localities by 2050. In an area analysis the outcome is a 57% reduction in suitable bioclimatic space by 2050.
This study establishes a fundamental baseline for assessing the consequences of climate change on populations of *H. elodes*. Specifically, it: (1) identifies and categorizes localities and areas that are predicted to be under threat from climate change now and in the medium term (2050), representing assessment priorities for *ex situ* conservation; (2) identifies 'core localities' that could have the potential to withstand climate change until at least 2050, and therefore serve as long-term *in situ* stocks for *H. elodes* genetic resources.

Key words - Climate change, *Hypericum*, MaxEnt, Species distribution modelling.

Riassunto - *Impatto del cambiamento climatico sulla distribuzione di* Hypericum elodes *L. (Hypericaceae): predire tendenze future e individuare le priorità.* In questo studio l'attuale e futura distribuzione di *Hypericum elodes* L. (Hypericaceae), una pianta Europeo-Atlantica caratteristica di stagni oligotrofici, è stata modellata in modo da facilitare appropriate decisioni per la conservazione, il monitoraggio e la ricerca. Utilizzando i metodi di massima entropia la distribuzione futuro è stata esaminata con il modello climatico HadCM3 nel corso dell'anno 2050.
H. elodes risulta una specie sensibile al clima, con una distribuzione W-europea e con netta preferenza per substrati acidi. Il modello mostra una marcata influenza negativa dei cambiamenti climatici. A livello di località, l'analisi indica una riduzione del 58% del numero di località pre-esistenti bio-climaticamente adatte per il 2050. L'analisi a livello di superficie indica una riduzione del 57% dell'area bioclimatica adatta per il 2050.
Questo studio stabilisce una base fondamentale per valutare le conseguenze dei cambiamenti climatici sulle popolazioni di *H. elodes.* In particolare, esso: (1) identifica e classifica le località e le aree che si prevede essere minacciate dal cambiamento climatico ora e nel medio termine (2050), che rappresentano le priorità di conservazione *ex situ;* (2) identifica località centrali che potrebbero resistere al cambiamento climatico almeno fino al 2050, e quindi servire come riserve *in situ* a lungo termine per *H. elodes.*

Parole chiave - Cambiamenti climatici, *Hypericum,* MaxEnt, Modelli distributivi.

Introduction

The observation of ecological properties of species and their areas of distribution being related is not new (Humboldt & Bonpland, 1807; Watson, 1835), but the increasing availability of information on the variation of environmental parameters in geographic space, species distribution data, and computation capacities, today allow large scale assessments of relationships between distributions observed and explanatory parameters. Relationships can be assessed by calculating "environmental" or "ecological" niches and their subsequent projection into geographic space (Guisan & Zimmermann, 2000). Here, GIS-based environmental data offer huge opportunities to assess variations in environmental factors within the species ranges, especially when combined with spatial modelling techniques. Species distribution models (SDMs) relate environmental variables to species occurrence records to gain insight into ecological or evolutionary drivers or to help predict habitat suitability across large scales (Elith & Leathwick, 2009). A diversity of modelling methods have been developed, ranging from rule-based descriptions to complex statistical or machine learning models. Their accuracy depends on the quality and quantity of the input data, from incidental sampling of occurrence records to more accurate presence-absence data (Franklin, 2010).
Habitat degradation and fragmentation, invasion by alien species, over-exploitation, and an ever-increasing human population are some of the important factors responsible for the species loss throughout the world (Barnosky *et al.*, 2011), bringing about 20% of

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the plant species at the risk of extinction (Brummitt & Bachman, 2010). A detailed knowledge on the current distribution of species is often a pre-requisite to rehabilitate the species in any ecosystem (Franklin, 2010). In this context, maximum entropy (MaxEnt) models (Phillips *et al*., 2006) have become an extremely popular tool to model the potential distribution of rare or threatened species, to separate ecological niches and to forecast future distributions under climate change (Kramer *et al*., 2013). MaxEnt uses the principle of maximum entropy to relate presence-only data to environmental variables to estimate a species' niche and potential geographical distribution (Phillips *et al*., 2006). MaxEnt is popular because it is easy to use and considered to produce robust results with sparse, irregularly sampled data and minor location errors (Elith *et al*., 2006).

Biodiversity decline is far greater in freshwater than in terrestrial ecosystems (Sala *et al*., 2000). As a consequence, in many countries, aquatic plants are among the most threatened organisms (Preston & Croft, 2001). In this work, the potential present-day and future distribution of the shallow soft-water pools specialist *Hypericum elodes* L. (Hypericaceae) will been examined. Soft-waters are notable category of freshwater habitat because of their biodiversity value and ecosystem services function. They have become increasingly rare resulting in the disappearance of the species from many sites (Arts, 2002) and consequently are protected by the European Council Directive 92/43/EEC of 21 May 1992 (Biondi *et al*., 2012). *H. elodes* is a good representative of this vulnerable habitat (Bilz *et al*., 2011) and a good candidate for studying how key species respond to climate change. In this context, this work will contribute to the European Strategy for Plant Conservation (ESPC).

The purpose of this study is to model the current distribution of *H. elodes*, and its future distribution under the influence of climate change until 2050, in order to identify priorities (for *in situ* and, and *ex situ* conservation, monitoring, and future research) and facilitate appropriate decision making.

Materials and Methods

Study species

Hypericum elodes is an Atlantic-European perennial herb belonging to the monotypic section *Tripentas* (Casp.) N. Robson, taxonomically isolated within the genus (Robson, 2012; Nürk *et al*., 2012). The reproduction of this species can successfully occur through a mixture of self- and cross-pollination (Carta *et al.,* 2015b); seeds germinate at the pond margins when water level drops and the diurnal thermal amplitude rises (Carta *et al.,* 2015a).

Area of study

The appropriate geographic extent of analysis should correspond to those areas that have been accessible by the species over relevant periods of time (Barve *et al*., 2011). Here, the study area comprises most of Europe, and part of North Africa. All data in this study have been projected to WGS84 and used at this coordinate system. The study area has the following coordinates (decimal degree): west = –10.5°, south = 30.2°, east = 42.0° and north = 71.6°.

Species records

Occurrence records have been compiled from multiple sources (scientific papers, monographs) but mainly they were downloaded from Global Biodiversity Information Facility (GBIF) website (http://www.gbif.org/). These data are considered reliable records; i.e. it can be safely assumed that they have been correctly identified and georeferenced. This will be an important point to take into account when selecting a threshold to obtain binary maps from the models (see below).

From this database the records dating from 1990 to 2011 were selected to match the occurrence data with land-cover data used in the analysis. Nonetheless, records were still heavily geographically unbalanced, with British Isles containing > 40% of all records (3720 records from a total of 8781) despite covering only about 16% of the extent of occurrence of the species (EOO, calculated as convex hull). In a second stage, the number of records was further reduced in British Isles by randomly selecting records to produce a sample with the same density as outside of British Isles. As 4372 records were detected outside of British Isles (3,075,671 km^2), 1189 records from British Isles (623,709 km^2) were included in the analysis. Finally, in order to eliminate a potential bias of duplicate occurrences for the same localities, the data sets were filtered so that there was only one record per 1 km^2 cell reported as centroid (this size was chosen to fit with the environmental layers cell dimension, see below).

Environmental input variables

Environmental variables were selected according to their potential biological relevance for the distribution of *H. elodes* (Table 1). The 19 bioclimatic variables together with elevation data (Digital Elevation Model), at 30 arc-seconds (about 1 km^2) of spatial resolution grid, were obtained from the WorldClim data set (http://www.worldclim.org; Hijmans *et al*., 2005). These variables include the temperature and precipitation parameters that are biologically most meaningful to define the eco-physiological tolerances of a species (Hijmans & Graham, 2006). The DEM data were used to generate slope (expressed

Table 1 - Environmental variables of potential biological relevance for the distribution of *Hypericum elodes.*

Bioclimatic variables and elevation data as provided by WorldClim data set http://www.worldclim.org	**Soil type categories as provided by HWSD** http://www.fao.org	**Land cover categories as provided by GLC2000 (simplified)** http://bioval.jrc.ec.europa.eu
Elevation	Acrisol - AC	Tree Cover, broadleaved, evergreen
Slope	Alisol - AL	Tree Cover, broadleaved, deciduous
Water distance	Andosol - AN	Tree Cover, needle-leaved
BIO1 = Annual Mean Temperature	Arenosol - AR	Shrub Cover, closed-open, evergreen
BIO2 = Mean Diurnal Range (Mean of monthly (max – min temp))	Anthrosol - AT	Shrub Cover, closed-open, deciduous
BIO3 = Isothermality (BIO2/BIO7) (* 100)	Chernozem - CH	Herbaceous Cover, closed-open
BIO4 = Temperature Seasonality (standard deviation *100)	Calcisol - CL	Sparse Herbaceous or Shrub Cover
BIO5 = Max Temperature of Warmest Month	Cambisol - CM	Regularly flooded Shrub and/or Herbaceous Cover
BIO6 = Min Temperature of Coldest Month	Fluvisol - FL	Mosaic: Cultivated/Cropland / Tree Cover / Other natural vegetation
BIO7 = Temperature Annual Range (BIO5-BIO6)	Gleysol - GL	Bare Areas
BIO8 = Mean Temperature of Wettest Quarter	Greyzem - GR	Water Bodies (natural & artificial)
BIO9 = Mean Temperature of Driest Quarter	Gypsisol - GY	Snow and Ice (natural & artificial)
BIO10 = Mean Temperature of Warmest Quarter	Histosol - HS	Artificial surfaces and associated areas
BIO11 = Mean Temperature of Coldest Quarter	Kastanozem - KS	-
BIO12 = Annual Precipitation	Leptosol - LP	-
BIO13 = Precipitation of Wettest Month	Luvisol - LV	-
BIO14 = Precipitation of Driest Month	Nitisol - NT	-
BIO15 = Precipitation Seasonality (Coefficient of Variation)	Podzoluvisol - PD	-
BIO16 = Precipitation of Wettest Quarter	Phaeozem - PH	-
BIO17 = Precipitation of Driest Quarter	Planosol - PL	-
BIO18 = Precipitation of Warmest Quarter	Podzol - PZ	-
BIO19 = Precipitation of Coldest Quarter	Regosol- RG	-
-	Solonchak - SC	-
-	Solonetz - SN	-
-	Vertisol - VR	-
-	Rock Outcrops - RK	-
-	Water bodies -WR	-
-	Urban, mining, etc. - UR	-
-	Glaciers - GG	-

in degrees). The presence of water may be essential because the plant is aquatic; thus, a "distance to water" map was created by calculating the euclidean distance of each cell from water sources (e.g. watercourse and standing water bodies as provided by Corine Land Cover 2000 (http://www.eea.europa.eu). Land cover categories were provided from http://bioval.jrc.ec.europa.eu (GLC2000). Soil type categories were provided from http://www.fao.org/nr/lman/abst/lman_080701_en.htm (HWSD).

Reducing multicollinearity

From the list of all collected variables those where Pearson's $r > 0.75$ were eliminated (Dormann *et al.*, 2012) (Table 2). The variable with the most correlations with the other variables was retained. This resulted in the inclusion of six climatic variables and all other environmental variables (see Table 3).

MaxEnt modelling and model evaluation

MaxEnt version 3.3.3a (https://www.cs.princeton.edu/~schapire/maxent/; Phillips *et al.*, 2006) was run with settings as follows: 75% presence records used for training, 25% for testing; maximum number of background points = 10,000; maximum iterations = 1,500; regularization multiplier = 1; replicates ran = 15 and mean relative occurrence or suitability probabilities predicted used for further analyses.

Table 2 - Correlation matrix of environmental variables of potential biological relevance for the *Hypericum elodes* distribution.

Pearson's moment correlation r matrix of input layers. All correlations were significant ($p < 0.05$). Bold: strongly correlating ($|r| > 0.75$) layers.

	BIO2	BIO3	BIO4	BIO5	BIO6	BIO7	BIO8	BIO9	BIO10	BIO 11	BIO 12	BIO 13	BIO 14	BIO15	BIO16	BIO17	BIO18	BIO19	Eleva-tion	Slope	Soil	Water	Land cover
BIO1	0.55	**0.75**	-0.47	**0.86**	**0.92**	-0.31	0.05	**0.85**	**0.91**	**0.95**	-0.09	-0.02	-0.26	0.33	-0.02	-0.22	-0.58	0.28	0.00	0.02	-0.46	0.02	0.25
BIO2		0.55	0.06	**0.78**	0.31	0.36	0.00	0.56	0.66	0.40	-0.41	-0.29	-0.53	0.48	-0.31	-0.51	-0.61	-0.10	0.33	0.04	-0.28	-0.02	0.11
BIO3			**-0.78**	0.50	**0.84**	-0.56	-0.31	**0.82**	0.49	**0.86**	0.15	0.14	-0.01	0.19	0.15	0.03	-0.42	0.45	0.32	0.24	-0.34	-0.02	0.17
BIO4				0.00	**-0.77**	**0.95**	0.44	-0.58	-0.06	-0.73	-0.48	-0.39	-0.35	0.09	-0.42	-0.39	0.06	-0.60	-0.22	-0.31	0.17	0.01	-0.11
BIO5					0.61	0.20	0.20	0.70	**0.98**	0.67	-0.40	-0.27	-0.55	0.47	-0.28	-0.52	-0.70	-0.02	-0.01	-0.10	-0.41	0.01	0.20
BIO6						-0.66	-0.14	**0.85**	0.67	**0.99**	0.16	0.16	-0.01	0.17	0.17	0.04	-0.42	0.47	0.06	0.14	-0.41	0.01	0.24
BIO7							0.36	-0.38	0.10	-0.59	-0.58	-0.45	-0.50	0.24	-0.48	-0.54	-0.15	-0.60	-0.08	-0.26	0.11	0.00	-0.10
BIO8								-0.35	0.25	-0.13	-0.38	-0.35	-0.19	-0.12	-0.36	-0.21	0.16	-0.56	-0.46	-0.39	-0.11	-0.01	0.01
BIO9									0.70	**0.88**	0.03	0.09	-0.24	0.39	0.09	-0.18	-0.67	0.46	0.29	0.22	-0.36	0.02	0.22
BIO10										0.73	-0.34	-0.22	-0.49	0.43	-0.23	-0.45	-0.65	0.03	-0.11	-0.12	-0.43	0.02	0.22
BIO11											0.10	0.12	-0.09	0.23	0.13	-0.03	-0.48	0.44	0.08	0.13	-0.42	0.01	0.24
BIO12												**0.91**	**0.81**	-0.26	**0.93**	**0.85**	0.60	**0.82**	0.22	0.41	0.07	-0.01	-0.10
BIO13													0.56	0.10	**0.99**	0.59	0.45	**0.84**	0.24	0.42	0.09	0.01	-0.12
BIO14														-0.68	0.58	**0.99**	**0.78**	0.45	0.07	0.24	0.05	-0.02	-0.07
BIO15															0.07	-0.67	-0.54	0.11	0.16	0.07	0.00	0.05	0.03
BIO16																0.62	0.47	**0.85**	0.23	0.42	0.08	0.01	-0.12
BIO17																	**0.75**	0.50	0.08	0.26	0.04	-0.02	-0.06
BIO18																		0.07	-0.06	0.09	0.22	-0.03	-0.19
BIO19																			0.27	0.43	-0.06	0.02	0.02
Eleva-tion																				0.61	-0.10	0.01	-0.03
Slope																					-0.06	0.01	-0.11
Soil																						-0.03	-0.13
Water																							-0.01

Table 3 - Selected bioclimatic variables and elevation data from theWorldClim data set and their percent contribution in MaxEnt model for *Hypericum elodes* in its distribution range.

Variable	Type of variable	Percent contribution	Permutation importance
BIO4 – Temperature seasonality (SD × 100)	Continuous	70.3	55.5
BIO1 – Annual mean temperature (°C)	Continuous	11.6	20.9
Soil type (29 categories, see Annex 1)	Categorical	10	7.8
BIO15 – Precipitation seasonality (coefficient of variation)	Continuous	3.6	5.9
BIO18 – Precipitation of warmest quarter (mm)	Continuous	1.9	4.3
Land cover (13 categories, see Annex 1)	Categorical	1.1	0.9
BIO12 – Annual precipitation (mm)	Continuous	0.6	3.4
BIO8 (Mean temperature of wettest quarter (°C)	Continuous	0.5	0.6
Water distance (euclidean)	Continuous	0.2	0.3
Elevation (m)	Continuous	0.2	0.3
Slope (°)	Continuous	0.1	0.1

MaxEnt estimates the distribution of maximum entropy constrained in such a way that expected values for predictor variables match their empirical average. Its logistic output can be interpreted as the relative environmental suitability of each pixel in relation to the background of the study area (Phillips *et al.*, 2006).

In order to calculate the area of occupancy (AOO), binary maps obtained from continuous probability models are required by setting a threshold value above which the location is considered suitable. To aid model validation and interpretation and to check for robustness of results, a 10th percentile training presence logistic threshold (10P) was used, because it was demonstrated to significantly improve the predictive ability for MaxEnt (Pearson *et al.*, 2007). To distinguish among sites with different suitability, thresholds were calculated to cut off at 10P, 20P and 30P presence logistic thresholds. These thresholds were used to classify each *H. elodes* locality, into 30P (optimal), 20P (intermediate; includes the 30P threshold), 10P (marginal; includes 30P and 20P thresholds).

Future mapping/climate change modelling

The model trained to obtain the present-day distribution has been projected by applying it to another set of bioclimatic layers with predicted future climate data in order to model *H. elodes* distributions under future climate conditions. The Met Office Hadley Centre (Hadley Centre for Climate Prediction and Research) climate change model, Hadley Centre Coupled Model, version 3 (HadCM3), a coupled atmosphere-ocean general circulation model, was used for the year 2050 under the lowest representative concentration pathway (RCP26) adopted by the IPCC for its fifth Assessment Report (AR5). Land cover was also included in the modeling because some reports assume that the general vegetation cover may stay intact and will remain so until 2080.

Results

Occurrence data

The locality data assembled from various sources amounted to a total of 8781 occurrences of *H. elodes*. The total data set was reduced to 1325 after filtering and recording only one record per 1 km^2 cell reported as centroid (Fig. 1). The EOO of *H. elodes* was 1,847,380 km^2. The AOO was 1271 km^2 (calculated as the number of 1 × 1 km cells where the species is present). The altitudinal range varied from 0 m (e.g. along the European Coast) to 1694 m (e.g. Asturias, Spain). The mean altitude was 168 m ± 226, with 74% (949 records) < 200 m, 16% (215 records) > 200 and < 500 m, 6% (88 records) > 500 and < 1000 (Massif Central, France), 1% (17) > 1000.

Present-day distribution

The MaxEnt model predicted the potential ecological niche for *H. elodes* with high success rates (regularized training gain = 1.7649) and scoring an AUC of 0.938 for both training and test data. The standard deviation of the test data was 0.003. The model included 6.8% cells grid with a low probability (< 0.4), 3.1% showed a medium probability (04 < p < 0.6) and only 0.48% showed a high probability (> 0.6) of suitable ecological niche (Fig. 1). The majority of presence pixels within the study area were captured in medium- (55.3%) and high-probability categories (31% of presence) while only the remaining 13.5% was in very low and low classes. The 10 percentile training presence logistic threshold was 0.35. By setting this value as threshold to define the minimum probability of suitable habitat the potential area of occupancy was 376,781 km^2. The 89.6% of presence pixels were included in this area.

MaxEnt selected two bioclimatic variables and soil data as the three most important predictors of *H. elodes* potential distribution (Table 3): BIO4 – "temperature seasonality (variation among monthly mean values)" (70.3%), BIO1 – "annual mean temperature" (11.6%) and Soil (10%). The MaxEnt model's internal jackknife test of variable importance (Fig. 2) showed that "temperature seasonality" (BIO4) was the environmental variable with highest gain when used in isolation. "BIO4" and Soil type were the environmental variables decreasing the gain more when omitted, and therefore they appeared to have the most information not present in the other variables. The optimum values of the selected variables were as follows: BIO4 ranging from 2.8 to 5.7 °C (Fig. 3), mean annual temperature between 7.5 and 12 °C (Fig. 3) and soil including Arenosol, Podzol and water bodies. On the contrary, soil categories such as Gleysol, Leptosol, Luvisol and Regosol negatively affected *H. elodes* predicted presence.

Climate change scenario

In the locality analysis the future modelled scenarios show a dramatic and profound decrease in the number of predicted bioclimatically suitable localities for *H. elodes*. Of the 1140 localities of 1271 included in the 10 percentile training presence logistic threshold the number is down to 468 by 2050, representing a reduction of 58% (Fig. 4).

As in the locality analysis, the area analysis is dominated by a significant reduction in predicted occurrence for *H. elodes* until 2050: from 376,781 km^2 to 161,579 km^2, representing a reduction of 57%. The area analysis also shows a general northward concentration through time (Fig. 5), due to the modelled occurrence of newly available bioclimatic space.

Discussion

As reported by Meusel *et al.* (1978), the species shows a typical W-European distribution (Atlantic corotype), occurring from the Iberian peninsula north to the British Isles, Netherlands and Germany. The disjoint occurrences should be added to this main distri-

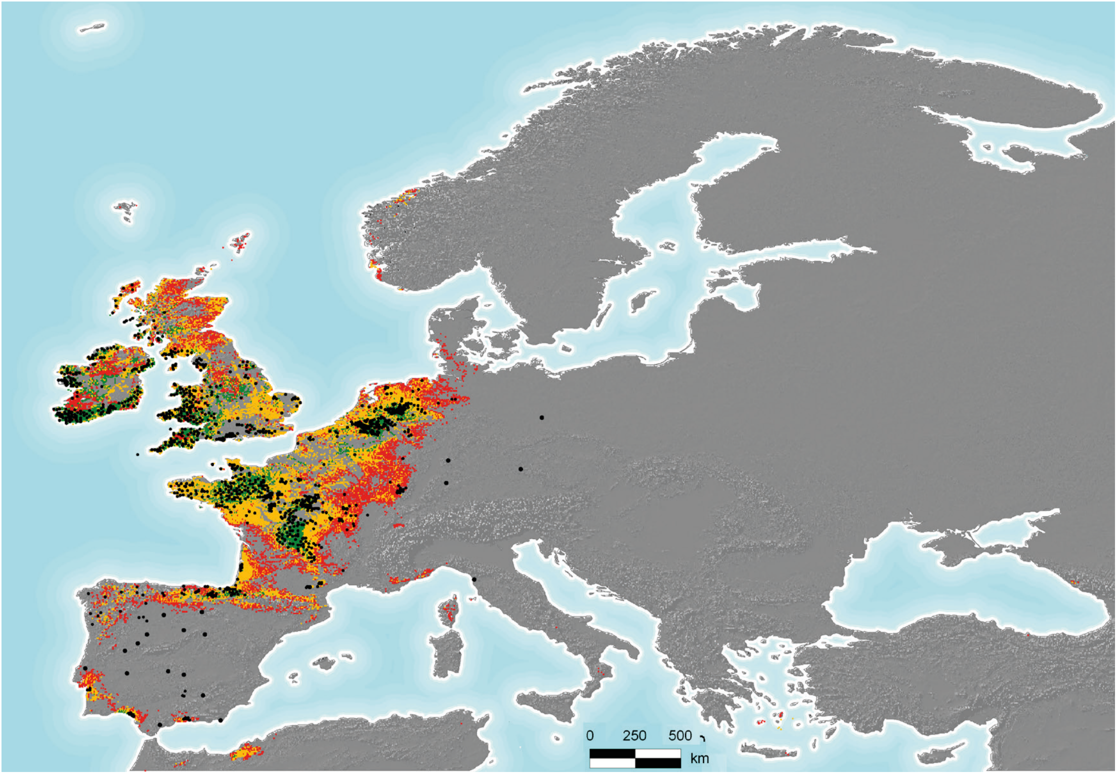

Fig. 1 - Predicted and actual distribution of *Hypericum elodes*. Black dots show recorded data-points. Coloured areas (red = marginal, yellow = intermediate, green = optimum) show predicted distribution based on MaxEnt modelling.

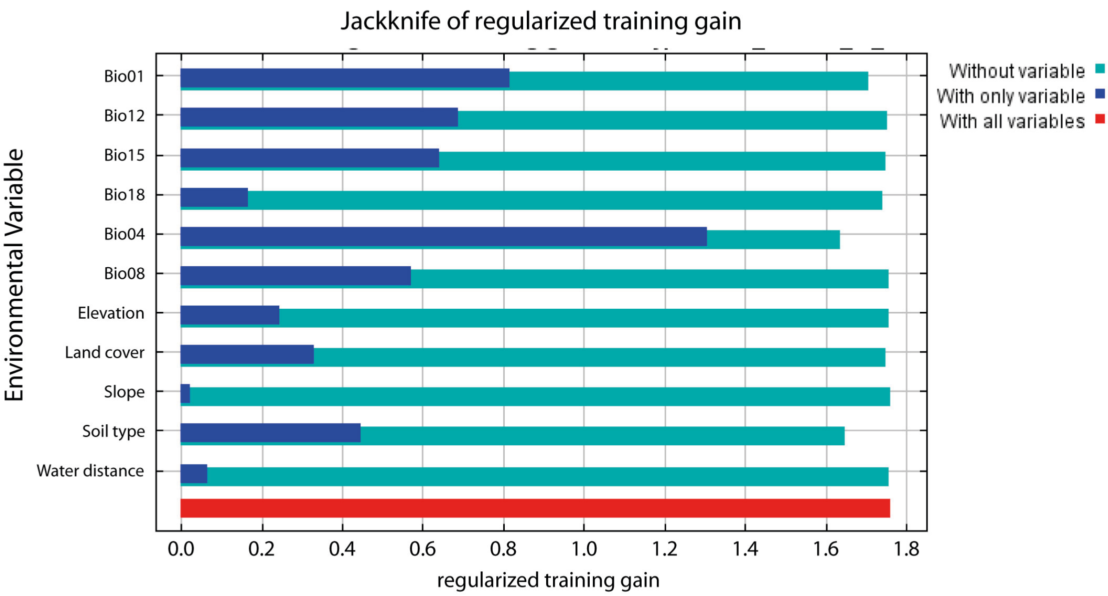

Fig. 2 - Results of jackknife evaluations of relative importance of predictor variables for *Hypericum elodes* MaxEnt model. In the histogram, dark blue bars indicate the regularized training gain for each variable when used in isolation and light blue bars show the same value when the variable is omitted. The environmental variable with highest gain when used in isolation is BIO4, which therefore appears to have the most useful information by itself. The environmental variables that decreases the gain the most when they are omitted are Bio04 and Soil type, which therefore appears to have the most information that isn't present in the other variables. Values shown are averages over 15 replicate runs.

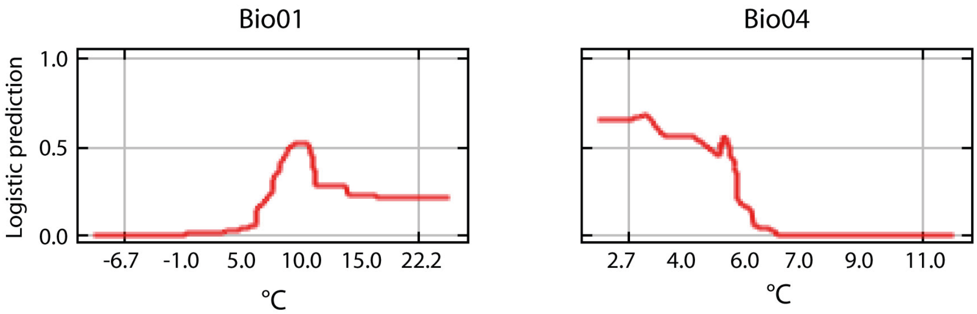

Fig. 3 - The response curves of environmental variables (WorldClim variables BIO1 and BIO4) affecting the MaxEnt prediction for *Hypericum elodes*. The curves show how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value.

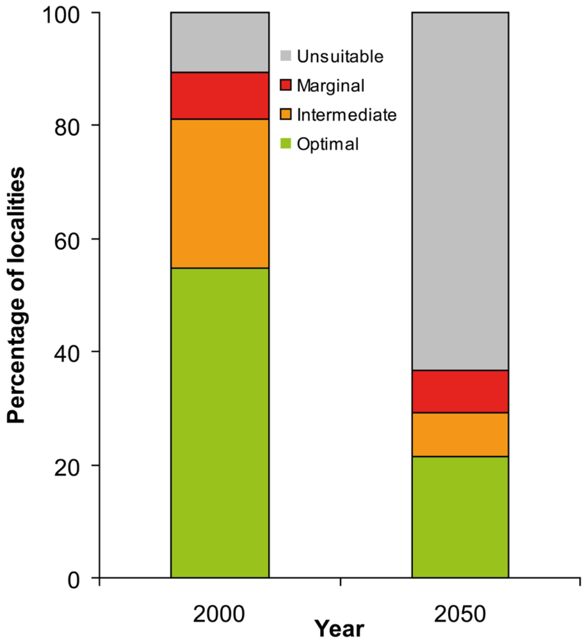

Fig. 4 - Predicted climate change outcomes for *Hypericum elodes* localities for the year 2050. Green = optimal; yellow = intermediate; red = marginal; grey = unsuitable bioclimatic localities.

butional range, thus extending the eastern border to central Germany and North-west Italy (Bedini *et al.*, 2011). Indeed, the species is believed to have moved southwards during the last glaciation. Then, as climate progressively became warmer and drier, the species migrated toward NW, looking for a more oceanic climate and leaving disjunct enclaves in areas with suitable micro-climatic factors (Corti, 1955; Carta *et al.*, 2011). Indeed, the most important variable in the MaxEnt model was the temperature seasonality (BIO4) which is an inverse measure of climate oceanity.
In this study, MaxEnt model predicted a potential distribution for *H. elodes* mainly based on few variables. However, the predictive present-day distribution model is assumed to be accurate and robust, due to the strength of the distribution model and robust agreement with ground-truthing.
Bioclimatic suitability for *H. elodes* is not a simple association with a linear temperature change but is heavily influenced by seasonality (BIO4). The response to monthly mean temperature is typical of the temperate climate present at latitudes of the study area. All predicted potential suitable areas are characterized by soil types with low pH values; indeed, this species is characteristic of acid pool fringe shallow-water swards (Murphy, 2002). For this reason, substrate represents a crucial factor in limiting the range of *H. elodes* and explains why all the area between North-East France and Belgium (mainly basic substrate), has been recognized by MaxEnt model as not suitable for this species despite the highly favourable climate.
The model suggests a profoundly negative trend for the future distribution of *H. elodes* under the influence of global climate change. Even if new localities are recorded, these are likely to represent a small proportion of those already known, based on the few remaining suitable areas for which we do not have occurrence records. New records are unlikely to influence the modelling, as performed here, to any considerable extent: the predicted percentage loss is unlikely to change dramatically. Some populations of *H. elodes* (occurring in optimal bioclimatic space such as North France, Netherlands and British Isles) might be able to resist climate change until 2050, at least in the absence of severely negative influences (e.g. land cover change). These populations may be defined as ‘core localities’ and they should be assessed as candidates for the long-term *in situ* conservation in the face of accelerated climate change. Conversely, those localities identified as marginally suitable in the present-day are suggested as priorities for *ex situ* conservation (Bedini & Carta, 2010; Guarino *et al.*, 2011).
Examination of the main protected areas of Europe shows that many populations already fall within established protected areas or Natura 2000 Network sites (data not shown). Thus, the knowledge gained from the current and potential modelled distribution can

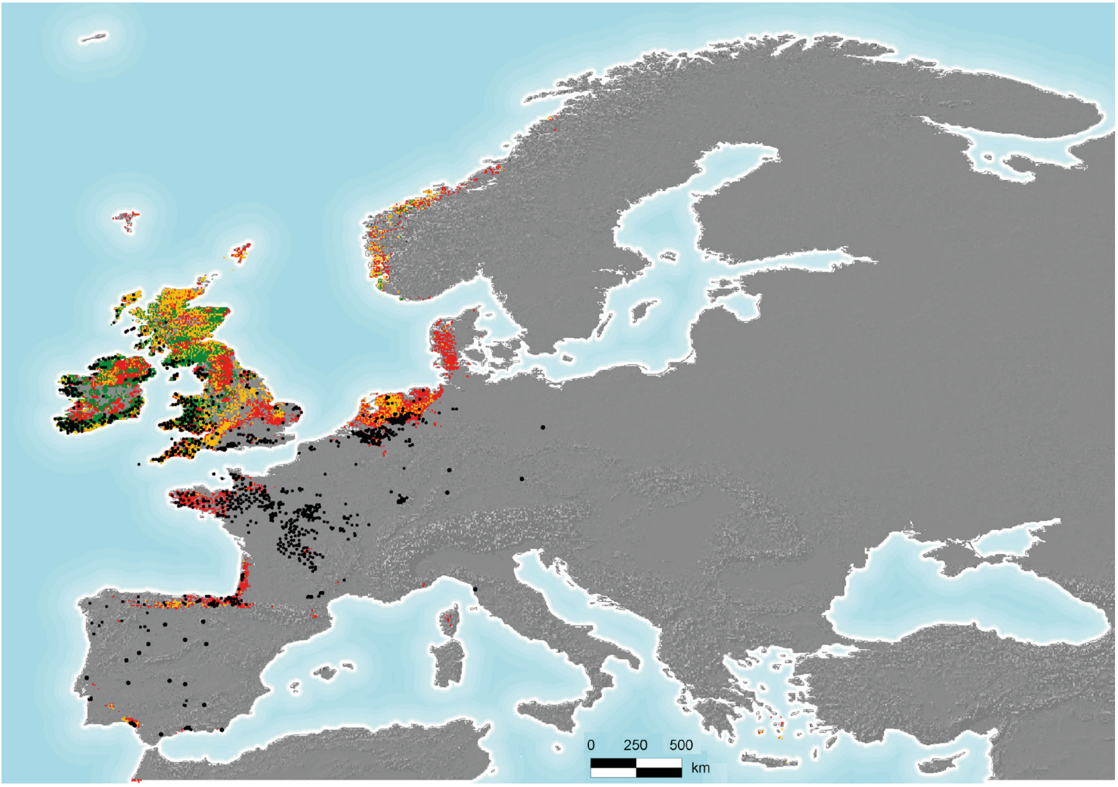

Fig. 5 - Predicted future distribution of *Hypericum elodes* in the year 2050. Black dots show currently recorded data-points. Coloured areas (red = marginal, yellow = intermediate, green = optimum) show predicted future distribution based on MaxEnt modelling.

be used to identify priorities and facilitate appropriate decision making for this species. This may be true for areas reported with optimal or intermediate suitability by the model, but at range margins of species distribution, the results may be not directly applicable. Indeed, local populations may be restricted to suboptimal environments distinct from the species' global range, which may be missed by continental models (such as those applied here). For this reason, at range margins of species distributions, regional models with precise data and conservative thresholds should be preferred over continental models with coarser resolution to identify suitable areas for peripheral populations (Vale *et al.*, 2014).
At the global level, the results may be useful to assess the conservation of the species by generating maps and reports of their protection status. For example, *H. elodes* is assessed to the Least Concern (LC) category of the International Union for Conservation of Nature (IUCN) because it is locally abundant and, at present, it does not show any sign of decrease all across its distributional range (Lansdown, 2011). However, using the results here obtained and applying the IUCN criteria E ("probability of extinction in the wild is at least 10% within 100 years", see IUCN, 2014) it is possible to propose to assess *H. elodes* as Vulnerable (VU).
Despite the limitations of assessing the impacts of climate change using the single species approach via bioclimatic modelling, this study has firmly established a baseline for assessing the consequences of climate change for *H. elodes*, and other plant species sharing the same vulnerable habitat. It is important to bear in mind that a single climate model (HadCM3), with one niche modelling method (MaxEnt) has been used here. Whilst the quantitative results could be quite different using other climate and niche models, I believe that the overall projections and trends will be similar with the present resources at hand.

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