STUDIA UNIVERSITATIS BABEŞ-BOLYAI BIOLOGIA, LXI, 2, 2016 (p. 95-106)

Climatic and habitat suitability of *Leontopodium alpinum* Cass. populations in the Romanian Carpathians

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SUMMARY. Species distribution models (SDMs) are widely used to obtain distributional knowledge in the context of incomplete biogeographic data sets. In this study we modeled the potential climatic niche of edelweiss in the Romanian Carpathians and the Alps for present and future environmental conditions. The prime objective of the study was to identify the possible impact of climate change over the distribution of this species with focus on the Carpathians. Ensemble models were fitted using the BIOMOD modeling tool in R software, for current conditions and two possible future scenarios (RCP pathways 6 and 8.5 for the year 2050). The results show that climate suitability is expected to decrease by 2050 in most of the locations considered in the study. These results outline the species sensitivity to climate warming, in agreement with previous studies.

Keywords: climate change, edelweiss, species distribution model (SDM).

Introduction

Leontopodium alpinum Cass*.,* commonly known as edelweiss, can be found in Asia and in Europe predominantly in the alpine area. Its European range is stretched from the Carpathian range in the East to the Pyrrenees in the West, and the Apennini and the Bulgarian mountains in the South (Tutin *et al*., 1976). In the Alps, edelweiss is found almost exclusively in the alpine area. In the Swiss Alps for example, species distribution models showed a high habitat suitability at high elevations, dry areas and steep slopes (Ischer *et al.,* 2014). In the Romanian Carpathians however, the species can be found as low as 440 m a.s.l. (the Lotrului Mountains). In a similar fashion to the Alps, the species is also distributed in the subalpine zone (e.g. the Piule-Iorgovanu Mountains, Gurgan area – 1900 m altitude), and in the alpine zone (e.g. the Bucegi Mountains, Omu Peak – 2500 m altitude). The species prefers rocky areas but it can also be found in mountain and alpine steep meadows, with calcareous substrate.

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Anthropogenic factors have caused a visible decrease of the species population in many European countries (IUCN Red List, 2003). The species is collected by tourists in many European countries as it is considered to be iconic for alpine flora. This situation led to early conservation measures in countries such as Switzerland, where the edelweiss has been protected since 1878, in Austria, since 1887 (Pop, 1939) and Slovenia, since 1896 (Skoberne, 2004). Currently, in Europe, the edelweiss is listed as *Least concern,* according to the IUCN Red List of Threatened Species, but the plant has strikingly different conservation statuses depending on the country where it occurs. Thus, the plant is listed as *Least Concern* in Switzerland (Moser *et al*., 2002), *Vulnerable* in Slovakia (Institute of Botany of Slovak Academy of Sciences, 2001), *Endangered* in Bulgaria (Petrova and Vladimirov, 2009) and Germany (Bundensamt für Naturschutz 2012), *Critically Endangered* in Ukraine (Kriscfalusy and Budnikov, 2007) and is protected in Montenegro. In Bulgaria, *in vitro* seed propagation methods have been used for *ex situ* conservation (Kozuharova, 2009).

In Romania, the negative effect of harvesting on edelweiss was observed by professor Alexandru Borza at the beginning of the 20th century. He took measures to protect edelweiss populations by declaring the plant a "natural monument" in 1933 (Borza, 1964).

Adding to the anthropic pressure, global temperatures have increased over the past hundred years by about 0.74ºC (1906 – 2005) (Trenberth *et al*., 2007). Following the temperature increase, plants are expected to migrate upwards on mountain slopes, a process associated with a reduction in available suitable habitat (Walther *et al*., 2005; Parolo and Rossi, 2007; Kumar, 2012; Gottfried *et al.,* 2012). A similar impact is expected for edelweiss, but its magnitude may be argued to be smaller, given the persistence of the species in low altitude locations across the Carpathian range. The article will try to assess all the known locations for the species in the Romanian Carpathians in regards to their climate suitability in current and future climate conditions. Our objective is to respond to the following questions: i) What is the current potential environmental niche for edelweiss in the Romanian Carpathians? ii) What is the impact of climate change on the potential niche? iii) What are the implications of these findings for the conservation of *Leontopodium alpinum*?

Materials and methods

Study area and distribution data

The Carpathians, part of the Alpine orogenic system, influence the climate, vegetation and soil through their altitude, fragmentation and structure (Badea *et al*., 1983). The presence of limestones and conglomerates generates a specific structural relief on the surface of which rocky meadows, preferred by edelweiss, are grouped.

Field activities were carried out in twelve mountains from the Romanian Carpathians (Fig. 1). 430 GPS presence points were collected in the Romanian Carpathians during the summer months of 2012 – 2015, with a Garmin 76 GPS unit. Additionally, 26 locations were extracted from existing literature (Iancu and Decenei, 1964; Pușcaru-Soroceanu and Pușcaru, 1971; Resmeriță, 1973; Frink, 2015; Frink *et al.,* 2015).

In order to build distribution models under climate change, we needed a more complete outlook on the ecological niche of the species. Aside from the Romanian Carpathians data, 1176 presence points were obtained for the Alps from several sources (www.infoflora.ch, University of Vienna Herbarium, www.gbif.org, Reist *et al.,* 1993; Freléchoux and Gallandat, 1995; Meyer, 1995; Mingard, 1996; Hoffer and Mingard, 1997; Mingard, 1997, Mingard and Moret, 1997; Mingard, 1998; Steiner, 2002; Ciardo and Jutzeler, 2007; Bornand, 2008 and foreign contributor).

The presence data was rasterized at 1 km which caused some points from the database to be eliminated as they had location errors above 1 km, or they occurred in the same raster cell. Therefore, 692 presence points from Alps and Romanian Carpathians entered the statistical modeling process, of which 43 points from Romania (from a total of 64 points).

Environmental data

Climatic predictors with a spatial resolution of 30 arc-seconds (~1km) were obtained from the *WorldClim* dataset (Hijmans *et al*., 2005). Topographic variables (slope, aspect, roughness, Topographic Ruggedness Index (TRI), Topographic Position Index (TPI) were calculated at the same resolution using the raster package (Hijmans *et al.,* 2005) in R 3.2.1 (R Core Team, 2011). The Topographic Wetness Index (TWI) was calculated in Saga GIS (Conrad *et al.,* 2015).

Information from all climatic and topographic variables was extracted for the 692 presences of the species (*raster* package, R 3.2.1 software). The importance of each predictor was tested using a generalized linear model (GLM) in which the predictors were also included in an exponential form, in order to incorporate some of the nonlinear correlation. In order to avoid multicollinearity, all predictors were tested for pair-wise correlation using Spearman's rho correlation coefficient (0.7 threshold).

For 2050, the climate variables were obtained also from WorldClim using the *Met Office climate* model (HadGEM2-ES) (Collins *et al.,* 2011) for two Representative CO_2 Concentration Pathways: RCP 6 and RCP 8.5 (Vuuren *et al.,* 2011). RCP 8.5 scenario describes the situation with the largest emissions of greenhouse and corresponds to a future characterized by the absence of mitigation policies. Under this scenario, there will be a considerable increase in these emissions leading to a radiative forcing of 8.5 W / m2 (Riahi *et al*., 2011). Regarding the RCP 6, greenhouse gas concentrations are predicted to grow until 2100 and then to decline (Toshihiko *et al*., 2011).

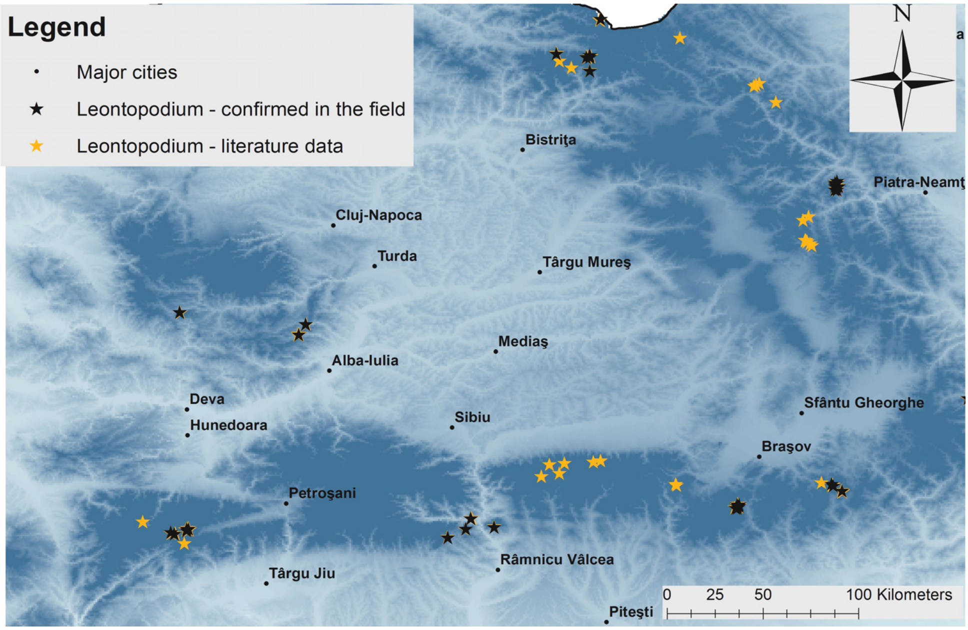

Figure 1. *Leontopodium alpinum* Cass. populations from the Romanian Carpathians considered for the current study

Modeling method

We used the BIOMOD modeling tool (*biomod2* package, R 3.2.1, Thuiller *et al.,* 2014) to fit the ensemble models for current and future conditions (2050). The ensemble models were built as an average of 9 distinct modelling methods: Generalized Linear Model (GLM), Generalized Boosting Model (GBM), Generalized Additive Model (GAM), Classification Tree Analysis (CTA), Artificial Neural Network (ANN), Surface Range Envelop (SRE), Flexible Discriminant Analysis (FDA), Multivariate Adaptive Regression Splines (MARS), and Random Forest (RF).

Information on the absence of the species was generated using the *biomod2* package, with the *sre* strategy (pseudo absences are selected outside of the broadly defined environmental conditions for the species). Ten times more absences than presences were used to create the model (Elith *et al.,* 2006; Massin-Barbet *et al*., 2012).

BIOMOD uses a repeated split-sample procedure keeping a part of the initial data out of the calibration for the subsequent validation of the predictions (Thuiller *et al.*, 2009). 10 repetitions were executed for each modeling method, with an 80/20 split (80% for calibration, 20% for validation).

Finally, all models were assembled into a single ensemble model based on their individual AUC scores (area under the receiver operating characteristic curve, Ogilivie and Creelman, 1968). The AUC has values between 0.5 (random predictions) to 1 (perfect models). A model is considered to be good if the AUC value is higher than 0.7 (Swets, 1988). An AUC of 0.7 was established as threshold (only models with AUC values above the threshold were used in the ensemble).

Habitat data

As edelweiss has a clear preference for base-rich soils, we used existing soil and geology maps for Romania (Florea *et al*., 1994; Murgeanu *et al.,* 1966-1970) to extract substrates which are favorable for the species (e.g. purely calcareous bedrocks, mixed bedrocks with limestone such as conglomerates, etc.). Edelweiss is also a light-demanding species (Ischer *et al.*, 2014). Therefore we applied a filtering layer with non-forested areas (Forest Europe 2011) to the layer with favorable substrate.

The data with potentially suitable habitat for the species was rasterized at the resolution of 30 arc-seconds (~1km). The information was not included in the models, and was used as a final step in the processing of the model output, to filter out areas with climate and topographic suitability which lacked a suitable substrate for the species.

Results and discussion

Four predictors were selected as relevant for the species (respecting the maximum collinearity threshold): two climate predictors (BIO3 - *isothermality*, and BIO5 - *maximum temperature of the warmest month*), and two topographic predictors (*roughness index* and TWI - *Topographic Wetness Index*). These predictors were used to build the models.

The climate and topographic model (masked with suitable habitat) for current conditions predicted a rather widespread potential distribution of edelweiss in the Romanian Carpathians (Fig. 2).

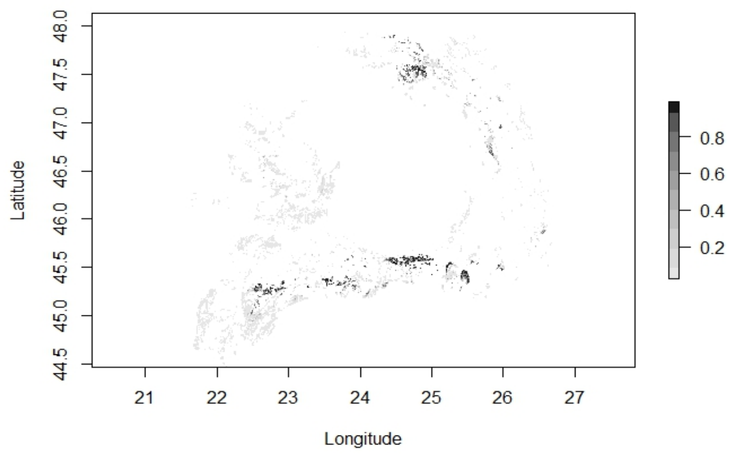

Figure 2. Species probability of occurrence in current climate conditions

As the species has an iconic status, and was intensively searched in all mountain ranges, we can assume to have quite complete information on its overall distribution in the Romanian Carpathians. We will limit all interpretations of climate change impact to the known locations of the species in the Carpathians. For these locations, we extracted the probability of occurrence in current and future climate conditions and the altitude – Table 1 (Hijmans *et al*., 2005).

According to the climate and topographic model, the highest probability for edelweiss occurrence (99%) is found above 2200 m (a.s.l.) in the Bucegi Mountains. The lowest probability is 5.8 % at 450 m (a.s.l.) in Obcinele Bucovinei. The model suggests the species is currently very near to its climatic limit in the Lotru Mts. (Doabrele), Trascău (Întregalde Gorges & Râmețului Gorges), Obcinele Bucovinei (Pietrele Lucinei), Căpățânii Mts., and locally in the Rarău Mts. (Vârful Rarău), the Ciucaș Mts. (Tesla) and the Hășmaș Mts.

Table 1.

Probabilities of edelweiss occurrence (%) for each known location and scenario

	Location	**Current cond.**	**RCP 6 (2050)**	**RCP 8.5 (2050)**	**Altitude (m a.s.l.)**
1	Bihor Mt. (Piatra Struțu)	27	5.5	4.8	936
2	Bucegi Mt. (Coștila)	99	91	77.8	2300
3	Bucegi Babele	84.8	17.9	4.7	2113
4	Bucegi Mt. (Cab.Caraiman I)	76.1	82.2	26.4	2022
5	Bucegi Mt. (Cab.Caraiman II)	99	90.4	75.6	2218
6	Bucegi Mt. (Caraiman I)	98.9	79.1	19.1	2075
7	Bucegi Mt. (Caraiman II)	98.7	77.5	22.7	2064
8	Căpățânii Mt.	27	8	7.4	901
9	Căpățânii Mt. (Narățu)	42.8	3.7	3.5	1348
10	Ceahlău Mt. 1	94.8	7.5	4.5	1670
11	Ceahlău Mt. (Detunatele)	91	4.6	4.5	1600
12	Ceahlău Mt. (Ghedeon)	61.1	13.2	4.3	1777
13	Ceahlău Mt. (Piatra cu apă)	83	4.7	4.2	1385
14	Ceahlău Mt. (Toaca 1)	92.4	4.9	4.3	1642
15	Ceahlău Mt. (Toaca 2)	90.3	4.5	4.4	1645
16	Ceahlău Mt. 2	92.1	5.1	4.8	1618
17	Ceahlău Mt.3	85.1	7.3	4.3	1688
18	Ceahlău Piatra Lată	87.7	4.1	4	1448
19	Ciucaș Mt. (Tesla)	26.5	3.5	3.4	1397
20	Ciucaș Mt. (Zăganu)	95.2	11.2	4	1723
21	Ciucaș Mt. I	76.5	6.1	3.7	1645
22	Ciucaș Mt. II	65.9	4.2	3.6	1799
23	Cozia Mt.	81.1	3.6	3.5	1296
24	Făgăraș Mt. (Culmea Podeanu)	98.8	48.4	7.8	1921
25	Făgăraș Mt. (Muchia Bâlea)	98.7	21.3	4.7	1939

	Location	Current cond.	RCP 6 (2050)	RCP 8.5 (2050)	Altitude (m a.s.l.)
26	Făgăraș Mt. (Piatra Caprei)	99	87.4	44.1	2240
27	Făgăraș Mt. (Trăsnita)	98.9	24.3	6.8	1896
28	Făgăraș Mt. (Turnurile Podragului)	98.4	8.6	4.4	1751
29	Făgăraș Mt. (Vârful Râios)	93.8	82.5	28.4	2291
30	Hăsmaș Mt. (Piatra Altarului)	38	3.4	3.3	957
31	Hăsmaș Mt. (Piatra Singuratică)	31.5	4.5	4.8	1485
32	Hăsmaș Mt. (Suhardu Mic)	35	3.4	3.3	974
33	Hăsmaș Mt. I	93.6	7.2	4.5	1686
34	Hăsmaș Mt. II	47.6	6.5	3.9	1667
35	Hăsmaș Mt. IV	22.9	4.3	4.1	1628
36	Hăsmaș Mt. Mt. III	90.1	4.8	5.1	1540
37	Lotru Mt. (Doabrele)	10.2	6.4	6	458
38	Maramureș Mt. (Coman)	86.7	4	4	1504
39	Maramureș Mt. (Farcău)	93.8	10.1	4.1	1750
40	Maramureș Mt. (Pop Ivan)	98.6	14.1	4.4	1783
41	Obcinele Bucovinei (Pietrele Lucinei)	5.8	3.5	3.5	1116
42	Piatra Craiului (zona Lespezi)	98.8	26.5	5.6	1812
43	Piatra Craiului Mt.(Umerii P.C.)	96.3	4.9	3.9	1635
44	Rarău Mt. (Pietrele Doamnei)	78.5	38	38	1513
45	Rarău Mt. (Popii Rarăului)	82.5	46	38	1285
46	Rarău Mt. (Varful Rarău)	28.3	38	36	1503
47	Retezat Mt. (Piatra Iorgovanului)	93.6	4.4	4.3	1801
48	Retezat Mt. (Piule)	98.9	20.3	6	1999
49	Retezat Mt. (Scorota I)	98.3	7.9	5.3	1850
50	Retezat Mt. (Scorota II)	71	23.5	7.1	1974
51	Retezat Mt. (Stănuleții Mari)	98.9	16.1	5.4	1966
52	Rodna Mt. (Cascada Cailor I)	88.3	5.3	5.4	1548
53	Rodna Mt. (Cascada Cailor II)	36.4	4.9	4	1248
54	Rodna Mt. (Corongiș)	93	6.7	4	1760
55	Rodna Mt. (Mihăiasa)	78.6	4.6	4.2	1645
56	Rodna Mt. (Obârșia Rebrei)	95.7	17.6	4.1	1917
57	Rodna Mt. (Turnu Rosu)	98.7	13.5	4.8	1774
58	Rodna Mt.(Valea Rea)	69.4	4.5	4.1	1385
59	Stănișoara Mt. (Bîtca Oblânc)	97	35	34	1163
60	Trascău (Întregalde Gorges)	23.9	4.7	4.3	814
61	Trascău (Râmețului Gorges)	21.4	7.8	6.8	722
62	Țarcu Mt. (Fața Fetii)	80.8	4.1	3.8	1517
63	Vâlcan Mt. (Oslea)	78.8	4	4	1747
64	Vrancea Mt. (Tișiței Gorges)	93	6.3	6.3	739

The two models for the year 2050 show a pronounced decrease of climate suitability for most of the known locations of the species. This decrease is more pronounced at lower than at the higher altitudes. In the RCP 6 scenario, the models suggest the species will be near its climatic limit in all of its locations from several massifs – such as Hășmaș, Vâlcan, Vrancea and Țarcu (adding to the previously mentioned ones). As expected, the RCP 8.5 scenario is more drastic and predicts a consistent decrease. In this "worst case scenario", the species will be in unfavorable climate conditions in most of its current locations, with the exception of high altitude populations such as those from the Bucegi or Făgăraș Mts., or, surprisingly, the somewhat smaller range of the Rarău Mts.

Currently, marginal populations of edelweiss persist in local environmental conditions which favor the species presence (e.g. the northern aspect of slopes and cold air currents). Small scale studies related to the viability of these populations are needed in such locations to help better understand the reason for the species resilience. These studies are even more necessary as in the next decades most of the *Leontopodium alpinum* populations from the Carpathians will be located in a sensibly warmer climate. Adding to this problem, the fragmented distribution of basic soils and the limited maximum altitude of limestone rock formations which harbor the species at lower altitudes suggest the need to establish monitoring sites for the species in multiple locations.

Conclusions

In case there is no significant change in CO_2 emissions, by the year 2050 many of the known locations for the species in the Carpathians will be near the limit of its climatic tolerance. The current study complements existing literature on this emblematic species by offering additional insight regarding the climate vulnerability of *Lentopodium alpinum* populations in the Romanian Carpathians. The results suggest there is justified concern related to the future of the species in Romania.

Therefore, we consider there is a strong need to monitor the species populations from low altitudes. Further research is needed to enhance the predictions of climate change impact on edelweiss. Physiological and demographical information could also be included in the models (Fordham et al., 2013), which would lead to a better understanding of species response to climate change.

These measures should be accompanied by public campaigns in order to create awareness among local communities. Awareness campaigns should focus on the threats the species faces, and should be doubled by punitive measures taken against any action which endangers the natural habitat of the species.

Symbol of the alpine meadows, edelweiss raises the interest and sympathy of the audience thus stimulating awareness for nature conservation. *Leontopodium alpinum* could represent a *flagship* species for the protection of vegetal associations in which it develops, as they are varied and rich in endemic species and also subjected to anthropogenic pressure. By protecting the habitats in which edelweiss occurs, many other rare or endemic species will benefit as well.

Acknowledgements

We thank Niklaus Zimmermann (WSL Birmensdorf, Switzerland) for the R code for GLM testing of variable importance. We also thank Federico Mangili from the University of Milan for providing presence points of *Leontopodium alpinum* from the Alps.

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