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CURRENT AND FUTURE POTENTIAL DISTRIBUTION OF GLACIAL RELICT *LIGULARIA SIBIRICA* (ASTERACEAE) IN ROMANIA AND TEMPORAL CONTRIBUTION OF NATURA 2000 TO PROTECT THE SPECIES IN LIGHT OF GLOBAL CHANGE

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Abstract: In the recent history, climatic changes have taken place at a planetary scale and organisms needed to adapt to these changes. The last glaciation is one of most documented climatic events responsible for the current distribution of living organisms. In the last two decades, conservationists have intensively discussed how extant organisms, some of which witnessed the last glaciation, will be able to cope with the new challenge: global warming. In this matter, several recently developed statistical algorithms (e.g., MaxEnt) and GIS techniques have been employed in species distribution modelling and identifying suitable conservation strategies. At the European level, the Natura 2000 network is one of the most extensive conservation strategies currently applied. But is this strategy always efficient? To respond to this main question we selected a typical glacial relict species (*Ligularia sibirica* (L.) Cass.) that is declining due to anthropogenic activities and which could also be influenced by global warming. We modelled the current and future distribution of the species in Romania using MaxEnt algorithm with bioclimatic data and investigated the efficiency of Natura 2000 in the long-term conservation of the target species. Our results showed that the niche of *Ligularia sibirica* has been conserved over time and is mostly influenced by cold and wet climate conditions. The projected climatic changes will not affect the future predicted distribution of the species' bioclimatic niche. We conclude that the efficiency of Natura 2000 in Romania for this species is less than optimal. In a broader conservation perspective, we recommend that information provided by species climatic distribution models (both present and future) should be taken into account to improve future protected area networks.

Keywords: MaxEnt, species distribution model, potential distribution, glacial relict, global warming, Natura 2000, Romania

1. INTRODUCTION

During the last glaciations the high amplitude of the climatic oscillations had an important impact on biodiversity. The average temperature in Greenland decreased rapidly (in only 10-20 years) by 10-14°C and lasted for 70-75 thousands of years (Dansgaard et al., 1993). The impact of the last glaciations was influenced by latitude and hypsometry and produced almost all the present biological variability (Hewitt, 2003, 2004). In Europe species had been forced to seek refuge into warmer regions (e.g. Iberian, Italian and Balkan Peninsulas or Carpathian Basin) (Provan & Bennett, 2008). Presently "old", relict species (i.e. species which have evolved over 10,000 years ago) are faced with new climatic changes, towards an overall global warming trend. As a result of industrial activities over the last decades, the global climatic changes have produced alterations in the distribution of biodiversity. The resulted changes represent an important challenge for conservationists (Thomas et al., 2004), which make use of various tools (such as Species Distribution Models [SDM] methods) for studying these effects at local and global scales (Guisan & Thuiller, 2005; Hu & Jiang, 2010). The recent progress in the development of SDM software, like MaxEnt (Phillips et al., 2006), makes possible predicting the distribution of endemic or rare species (Gibson et al., 2007; Loarie et al., 2008; Raes et al., 2009; Saupe et al., 2011; Wilson et al., 2011), habitats (Riordan & Rundel, 2009), or even diseases (Kouam et al., 2010) and pathogenic organisms (Rödder et al., 2010; Puschendorf et al., 2009; Murray et al., 2011; Apostolopoulou & Pantis, 2009), and assists in evaluating the potential impact of global changes on biodiversity (Thomas et al., 2004; Thuiller, 2004; Cheung et al., 2009; Conroy et al., 2011).

In the light of these anthropogenic changes and impacts on biodiversity, the European Network of protected areas, Natura 2000, was created to preserve the key areas for indigenous habitats, plants and animals (Maiorano et al., 2007). At the European level, the efficiency of Natura 2000 cannot be asserted yet because of issues related to the implementation of management plans, the short time since these have been proposed, and financial problems (Fontaine et al., 2007; Hajek et al., 2010; Cogălniceanu & Cogălniceanu, 2010). Iojă et al. (2010) evaluated Romanian Natura 2000 network from the perspective of an underrepresented segment of Romanian biodiversity, the local flora.

One of the main problems concerning the conservation of Romanian plants is the insufficiently documented distribution of the species (Sârbu, 2007; Sârbu et al., 2007; Primack et al., 2008; Martin-Lopez et al., 2009). The aim of this study is to produce a model of the distribution of the endangered *Ligularia sibirica* (L.) Cass. in and to analyze: (1) the potential distribution of the species in Romania; (2) the vulnerability of the species bioclimatic niche with regards to the global climatic change at a local scale; (3) the efficiency of the present Natura 2000 network over time; and (4) the bioclimatic profile of the species in a typical mountain environment.

2. MATERIAL AND METHODS

2.1. Study species and area

The genus *Ligularia* Cass. includes 129 species, most of which are distributed in Asia, with Eastern Asia having the highest concentration of species (119), representing 96% of the genus, and central China being considered as the original area for *Ligularia* (Liu et al., 1994). It is assumed that the genus *Ligularia* appeared in mid-Cretaceous and its dispersal routes extended mainly along the mountains in southern Asia, with a few species dispersing to northeast Asia (Liu et al., 1994). Only two species, *L. sibirica* (L.) Cass. (Fig. 1) and *L. glauca* (L.) O. Hoffm. colonized Europe (Chater, 1976; Liu et al., 1994).

Figure 1. *Ligularia sibirica* (L.) Cass. (ROSCI0086 Găina-Lucina, Suceava County)

Currently, *L. sibirica* has a wide Euro-Siberian distribution range. The main continuous distribution range is from East Asia (Japan, Korea, China and Mongolia) to southern Siberia and to the European part of Russia, Byelorussia, and Ukraine (Ohwi et al., 1965; Liu et al., 1994; Kukk, 2003a; Minayeva et al., 2005; Liu et al., 2006). In Europe, a few separated populations persist in Estonia, Latvia, Poland, Hungary, Romania, Croatia, Bulgaria, the Slovak Republic, the Czech Republic, Austria, and France (Poiarkova, 1961; Chater, 1976; Fain, 1995; Kukk, 2003a; Hendrych, 2003; Bensettiti et al., 2002; Pakalne & Kalnina, 2005; Šegulja, 2005; Petrova, 2010; Šmídová et al., 2011). The species was also found in the Asian part of Turkey (Eastern Anatolia) (Erik, 1990; Ocakverdi, 2001). The localities in these countries are rather distant and separated from the continuous distribution range of the species. They originated most likely in the early postglacial period and thus represent rare remnants of a former continuous distribution (Šmídová et al., 2011). Therefore, *L. sibirica* is considered to be a postglacial relict (Hendrych, 2003) and it is classified as a ‘Rare’ species in Romania (Oltean et al., 1994; Oprea, 2005). This species is also protected by EU Habitat Directive, Annex II of the Council of European Communities (1992).

Sample records (90) of *L. sibirica* in Romania were obtained from literature and personal field observations (Fig. 2). The records were georeferenced using ArcGIS 9.3 software (ESRI Inc.) in the Romanian national coordinate system (Dealul Piscului 1970).

2.2. Variable data

We used 19 high-resolution bioclimatic variables (Table 1) to develop present-day and future predictive models. The two future climate scenarios (A2a and B2a) were used for three time frames: 2020, 2050, and 2080. The bioclimatic data were downloaded from the WorldClim website (Hijmans & Graham, 2006, http://www.worldclim.com/, accessed on December 12, 2010). The present-day climate datasets were developed by Hijmans et al., (2005) and the future climate model by the Hadley Climate Centre (HadCM3 model; Collins et al., 2001). The data has fine resolution (30 arc second) and global coverage. We extracted the climate datasets for the Romanian territory in ArcGIS 9.3, maintaining the original resolution for quality preservation. For the extraction of the Natura 2000 niche of *L. sibirica* we used a shapefile delineating Romanian Natura 2000 sites (available on The Romanian Ministry of Environment site, http://www.mmediu.ro/; accessed on December 12, 2010).

2.3. Ecological niche modelling methodology

The SDMs were produced using MaxEnt version 3.3.3 (Phillips et al., 2006; Phillips & Dudík, 2008), a machine-learning algorithm which generates the potential distribution of species using known occurrence records and background (non-presence) samples to reduce the entropy between occurrence data and background.

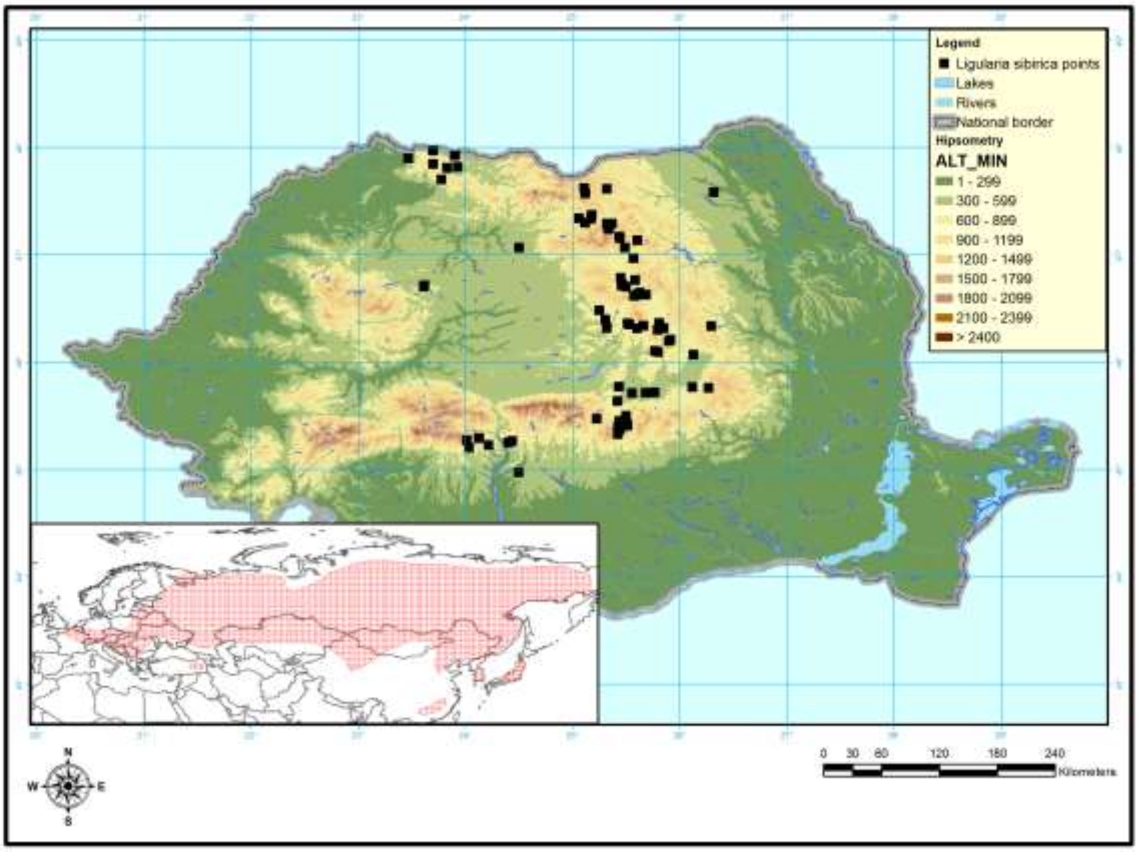

Figure 2. General distribution of *Ligularia sibirica* in the world (after Liu et al., 1994, modified by us) and in Romania (training samples utilized for our modelling)

The modelling was made with default settings, for future predictions using the "projection" function from MaxEnt.

We assessed ecological similarities between the present-day and future predicted distributions using ecological coefficients implemented in the application ENMTools version 1.1 (Warren et al., 2008): for niche breadth the Levins coefficient (1968) was calculated; for niche overlap we calculated two different statistics (implemented in the ENMTools program): Schoener's D (Schoener, 1968) and I (see Warren et al., 2008 for more details). Both niche overlap statistics (I and D) range from 0 (no niche overlap) to 1 (perfect overlap of the niches).

The predictive power of the SDMs using MaxEnt was found as most competitive among machine-learning algorithms used to predict SDMs (Elith et al., 2006). The model performance was assessed by calculating AUC ROC scores (Area Under [Receiver Operating Curve] Curve), an approach widely used in ecological modelling, MaxEnt included. Swets (1988) proposed three categories of model performance based on AUC value ranges: 'excellent' when > 0.9, 'good' when > 0.8 and 'useful' when > 0.7. In addition, this model-testing method is non-parametric and therefore, it is highly recommended (Pearce & Ferrier, 2000) and frequently used (e.g. Hartel et al., 2010) for ecological applications.

For statistical tests (ANOVA Kruskal-Wallis) between variables we used the XLStat Pro 2010 statistical add-on for Microsoft Office XL 2007.

3. RESULTS AND DISCUSSIONS

3.1. Model compression and variable contribution

Based on ROC tests, the predictive power of models generated was excellent: AUC values exceed 0.9 (0.9312) (Table 1). The variables who gained the most importance during the model generation are "BIO1", "BIO6" and "BIO15" (Table 1, Table 2). These variables represent low temperatures and high moisture and suggest a strong ecological preference for wet bioclimatic zones and relatively cold areas (like depressions from Eastern Carpathians). The descriptive statistics for all distribution records of *L. sibirica* are presented in Table 2. There were significant differences among the values of the variables "BIO1", "BIO6" , and "BIO15" for present-day models ("present"), "2080 A2a", and "2080 B2a" models (BIO1: Kruskal-Wallis $Q_{(2)}=173.18$, $p_{(general)}< 0.0001$, $p_{(posthoc)}<0.0001$; BIO1: Kruskal-Wallis $Q_{(2)}= 180.145$, $p_{(general)}< 0.0001$, $p_{(posthoc)}<0.0001$; BIO1: Kruskal-Wallis $Q_{(2)}= 140.663$, $p_{(general)}< 0.0001$, $p_{(posthoc)}<0.0001$).

Table 1. Variable descriptions and their contribution for generation of SDMs

Variable code	Variable description	Variable contribution (%)
BIO1	Annual Mean Temperature	15.2114
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	2.2732
BIO3	Isothermality (P2 / P7) (* 100)	1.9291
BIO4	Temperature Seasonality (standard deviation *100)	7.0576
BIO5	Max Temperature of Warmest Month	0
BIO6	Min Temperature of Coldest Month	16.1142
BIO7	Temperature Annual Range (P5-P6)	0.7174
BIO8	Mean Temperature of Wettest Quarter	0.4128
BIO9	Mean Temperature of Driest Quarter	1.7928
BIO10	Mean Temperature of Warmest Quarter	39.8111
BIO11	Mean Temperature of Coldest Quarter	0
BIO12	Annual Precipitation	0
BIO13	Precipitation of Wettest Month	0.4092
BIO14	Precipitation of Driest Month	1.4179
BIO15	Precipitation Seasonality (Coefficient of Variation)	10.1741
BIO16	Precipitation of Wettest Quarter	0
BIO17	Precipitation of Driest Quarter	0
BIO18	Precipitation of Warmest Quarter	0
BIO19	Precipitation of Coldest Quarter	2.6792

The niche model we report here is conservative; the areas predicted suitable for *L. sibirica* are the same as the ones reported in the literature. By comparing present bioclimatic data with 2050 and 2080 models, it can be noticed that although there are statistically significant differences and the tendency is toward climate warming and rainfall diminishing, the ecological niche preserves its "cold" and "wet" characteristic with low thermal amplitude (about 10°C between annual mean min./max. temperature) (Table 2).

Table 2. Variables response at training points of distribution of *Ligularia sibirica*

Variable code	Descriptive statistics: mean ± standard deviation (min. / max.)						
	Present	2020A	2050A	2080A	2020B	2050B	2080B
BIO1	6.346±1.665 (-0.4/9.2)	7.728±1.680 (0.8/10.6)	9.437±1.669 (2.5/12.3)	11.551±1.664 (4.6/14.4)	8.536±1.677 (1.6/11.4)	9.179±1.668 (2.3/12.1)	10.067±1.665 (3.2/13)
BIO2	9.560±0.592 (6.9/10.8)	10.043±0.597 (7.4/11.3)	10.283±0.609 (7.6/11.5)	10.665±0.608 (8/11.9)	10.085±0.613 (7.4/11.3	10.302±0.605 (7.6/11.5)	10.357±0.611 (7.6/11.6)
BIO3	30.596±0.699 (28/32)	29.236±0.618 (27/30)	28.528±0.620 (26/29)	27.989±0.590 (25/29)	29.326±0.667 (27/31)	28.944±0.588 (26/30)	28.449±0.636 (26/29)
BIO4	7541.449±341.188 (6128/8187)	7.926±344.473 (6568/8485)	8087.315±331.016 (6833/8709)	8434.303±384.994 (7240/9229)	7625.416±334.396 (6358/8248)	7974.865±329.242 (6672/8547)	8407.056±335.334 (7102/97)
BIO5	21.663±2.397 (11.4/25.7)	25.357±2.392 (15/29.7)	28.883±2.368 (18.6/33.3)	32.424±2.356 (22.1/36.7)	26.650±2.385 (16.3/31.1)	28.285±2.375 (18/32.7)	30.121±2.371 (19.8/34.5)
BIO6	-9.015±1.066 (-12.4/-6.6)	-8.338±1.102 (-12/-5.7)	-6.544±1.091 (-10.2/-3.9)	-5.090±1.048 (-8.8/-2.6)	-7.217±1.066 (-10.9/-4.7)	-6.788±1.103 (-10.4/-4.2)	-5.561±1.037 (-9.2/-3.3)
BIO7	30.721±1.545 (23.9/33.7)	33.696±1.550 (27/36.7)	35.390±1.564 (28.8/38.4)	37.522±1.573 (30.9/40.5)	33.776±1.565 (27.2/36.9)	35.073±1.576 (28.4/38)	35.771±1.557 (29/38.8)
BIO8	14.085±2.045 (5.5/17.3)	15.404±2.042 (6.7/18.8)	12.852±2.053 (4.2/16.1)	14.973±2.041 (6.5/18.4)	15.193±2.132 (6.8/18.7)	14.346±2.983 (3.9/18.8)	15.111±3.040 (5.2/20.2)
BIO9	-2.378±1.347 (-6.1/0.9)	0.220±3.936 (-2.8/16.4)	5.617±6.301 (-0.5/19.1)	16.926±3.601 (3.4/21.8)	6.111±4.587 (-1.1/17.3)	9.289±6.071 (-0.3/19.2)	11.722±4.394 (4.7/20.3)
BIO10	15.545±2.011 (7/18.7)	17.502±2 (9.1/20.9)	19.754±1.958 (11.6/23.4)	22.335±1.937 (14.4/26)	18.076±1.981 (9.9/21.6)	19.289±1.923 (11.3/22.8)	20.706±1.984 (12.5/24.3)
BIO11	-3.743±1.212 (-8.4/-1.5)	-2.854±1.223 (-7.6/-0.5)	-0.994±1.187 (-5.7/1.2)	0.933±1.193 (-3.9/3.1)	-1.421±1.213 (-6.3/0.8)	-0.989±1.202 (-5.6/1.2)	-0.887±1.205 (-5.5/1.3)
BIO12	712.921±95.186 (590/1023)	672.258±93.240 (549/962)	663.494±94.754 (536/949)	631.325±92.651 (605/906)	673.775±93.356 (552/963)	669.888±96.628 (541/962)	682.292±99.343 (551/985)
BIO13	107.258±95.186 (92/142)	102.843±12.505 (85/130)	91.056±10.617 (73/116)	82.337±9.991 (69/104)	96.573±11.356 (79/122)	93.753±11.157 (79/120)	90.809±10.728 (75/117)
BIO14	34.371±7.318 (24/53)	31.787±5.038 (23/45)	33.562±5.665 (24/48)	33.763±4.342 (26/46)	32.933±5.619 (24/48)	35.899±5.057 (27/47)	34.539±5.699 (24/50)
BIO15	42.774±5.644 (27/52)	43.427±5.772 (32/56)	35.697±4.010 (29/46)	32.865±3.889 (25/44)	39.135±5.128 (28/50)	34.607±3.939 (27/45)	30.910±3.934 (25/42)
BIO16	293.978±34.274 (251/399)	282.326±33.312 (227/366)	256.697±31.186 (215/343)	233.416±28.520 (193/305)	267.022±31.204 (219/352)	252.348±29.649 (214/339)	243.292±29.117 (206/322)
BIO17	108.607±22.407 (76/175)	105.663±21.211 (74/162)	114.528±17.677 (83/158)	107.551±13.174 (88/146)	111.663±17.215 (81/154)	117.809±17.052 (86/161)	118.382±17.072 (90/166)
BIO18	286.045±33.407 (238/390)	255.056±29.437 (201/318)	203.966±22.984 (161/252)	153.135±16.458 (124/205)	227.697±25.516 (176/288)	164.798±22.246 (129/211)	212.045±23.405 (173/262)
BIO19	114.584±27.184 (76/193)	116.551±28.560 (74/202)	133.955±32.951 (87/224)	138.011±33.683 (90/233)	123.764±30.122 (81/206)	137.270±33.424 (89/229)	146.798±36.2 (95/246)

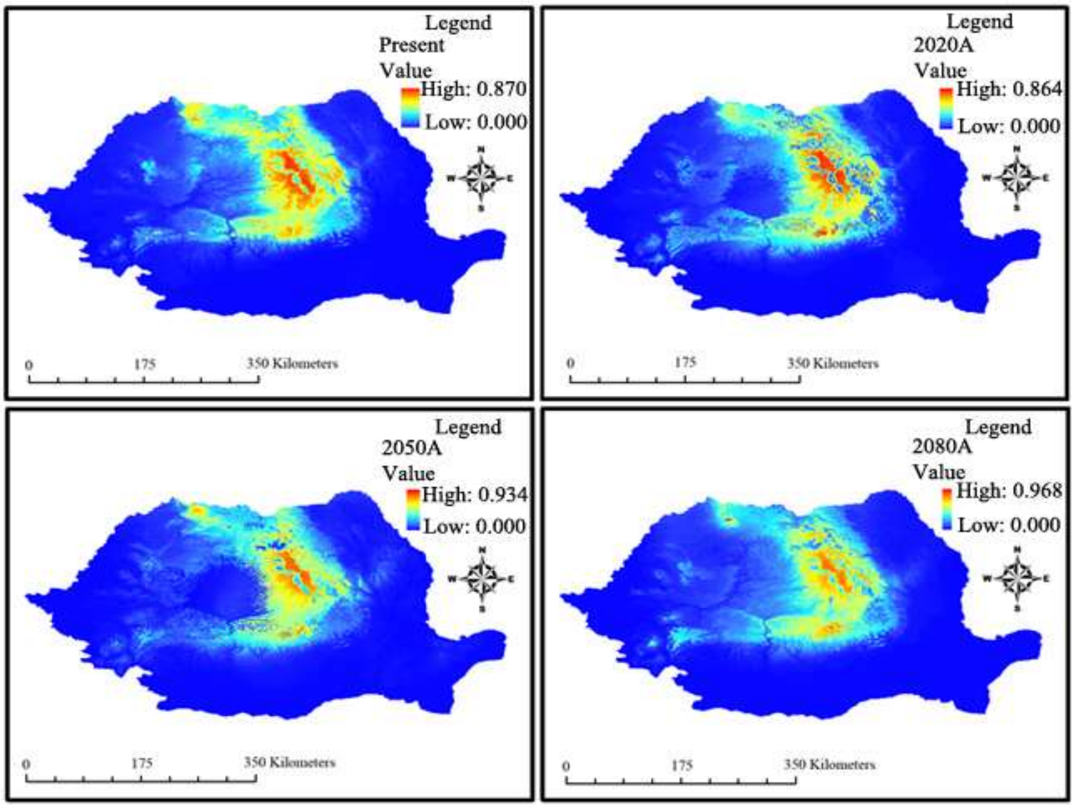

Figure 3. Potential distribution of *Ligularia sibirica* under current and future environmental conditions (scenario A2a)

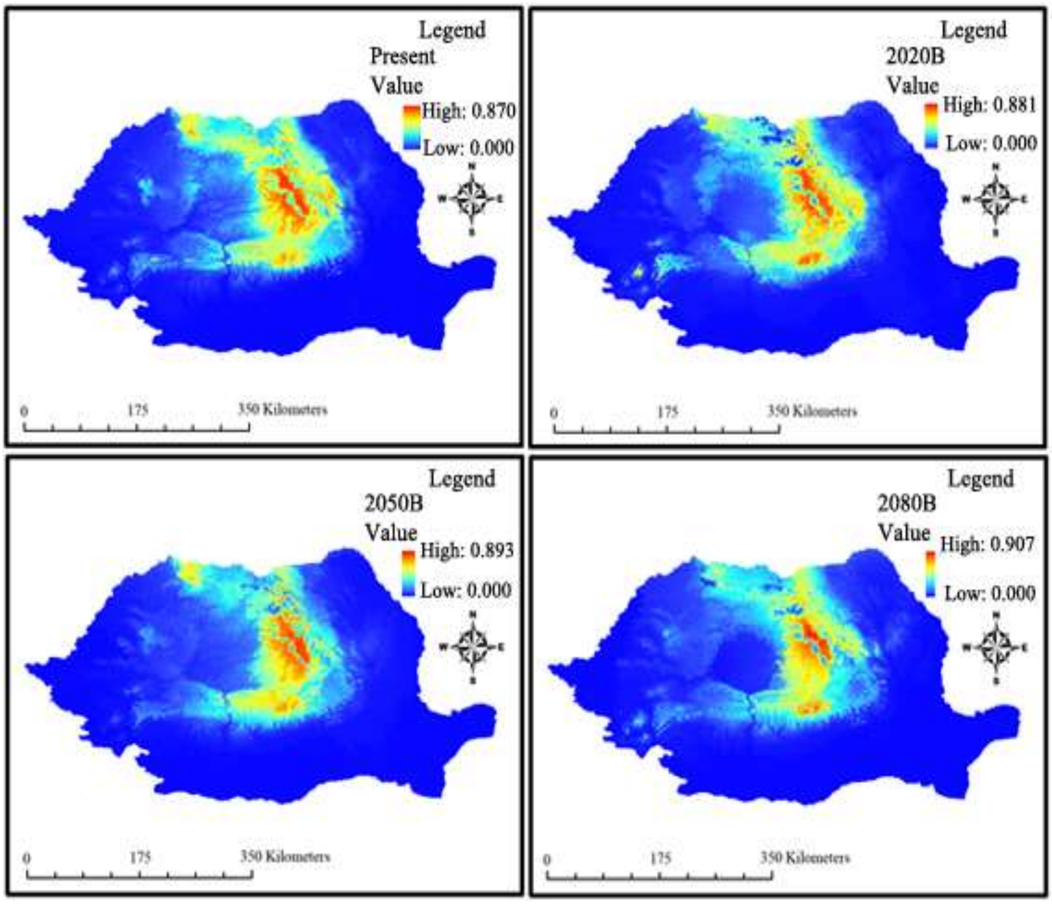

Figure 4. Potential distribution of *Ligularia sibirica* under current and future environmental conditions (scenario B2a)

The precipitation range (536-605 mm/906-1023 mm/year) corresponds to that of the habitat types this species occupy in Romania, mountain and sub-mountain environments (500-600 mm/1000-1200 mm/year, for 1961-2000 period: Dragotă & Baciu, 2008). These results can also be correlated with the meso–hygrophilous character of *L. sibirica*, which inhabits wet meadows and swamps maintained by cold springs.

The most suitable areas for *L. sibirica* are present in Maramureş, Suceava, Harghita, Covasna and Braşov counties of Romania but suitable areas were also identified in the Eastern and Central parts of the Southern Carpathians (Fig. 3).

The analysis of the niche breadth variation in relation to the models suggests a conservative trend for scenario "A2a" r^2=0.019 and for scenario "B2a" r^2=0.250 (Fig. 4).

Overall, the niche overlap statistics (both D and I) show no differences between models (Tables 3 and 4), providing further support for constancy and conservatism of *L. sibirica* niche in its southern limit of distribution.

3.2. Efficiency of Natura 2000 network

Currently the present Natura 2000 covers only 33.76% of the *L. sibirica* potential niche and the majority of the protected regions are situated in the central and the southern range of distribution (Harghita, Braşov and Prahova counties), representing only a small fraction of the potential distribution area in Romania, which may render the protection of the species rather inefficient (Fig. 5). The potential distributional area protected in Natura 2000 is significantly smaller compared to current and future total potential distribution (Table 5).

Table 3. Schoener's D (left) and Warren et al. (2008) I (right) niche overlap statistics for the "A2a" scenarios

Models	present	2020a	2050a	2080a
present	0	0.7689	0.7614	0.7891
2020A	0.7689	0	0.8224	0.8350
2050A	0.7614	0.8224	0	0.8057
2080A	0.7891	0.8350	0.8057	0

Model	present	2020a	2050a	2080a
present	0	0.8360	0.8189	0.8497
2020A	0.8360	0	0.8553	0.8805
2050A	0.8189	0.8553	0	0.8547
2080A	0.8497	0.8805	0.8547	0

Table 4. Schoener's D (left) and Warren et al. (2008) I (right) niche overlap statistics for the "B2a" scenarios

Models	present	2020b	2050b	2080b
present	0	0.7844	0.7938	0.7910
2020B	0.7844	0	0.8448	0.8495
2050B	0.7938	0.8448	0	0.8563
2080B	0.7910	0.8495	0.8563	0

Models	present	2020b	2050b	2080b
present	0	0.8446	0.8551	0.8433
2020B	0.8446	0	0.8920	0.8918
2050B	0.8551	0.8920	0	0.8979
2080B	0.8433	0.8918	0.8979	0

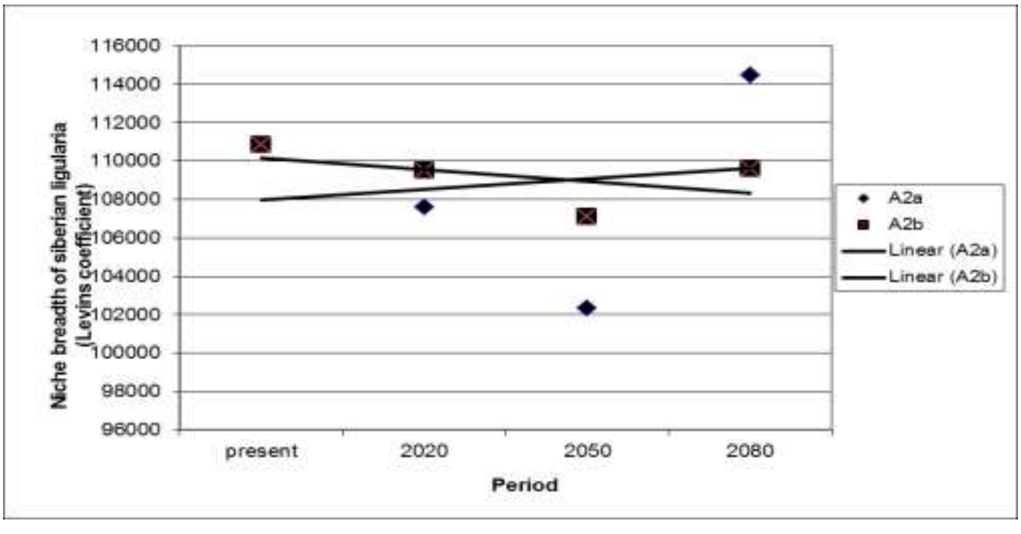

Figure 5. Niche breadth response to current and future environmental conditions of *Ligularia sibirica*

Table 5. Evolution in time of niche coverage in protected areas Natura 2000 for *Ligularia sibirica*

model	Percent of Coverage (%)	χ^2	DF	p-value
Natura 2000 present	33.76	20.462	1	< **0.0001***
Natura 2000 2020A	33.75	20.471	1	< **0.0001***
Natura 2000 2050A	31.80	22.214	1	< **0.0001***
Natura 2000 2080A	33.87	20.366	1	< **0.0001***
Natura 2000 2020B	31.71	22.294	1	< **0.0001***
Natura 2000 2050B	32.47	21.596	1	< **0.0001***
Natura 2000 2080B	31.54	22.453	1	< **0.0001***

* significant differences in our comparisons

4. CONCLUSIONS

4.1. Natura 2000 efficiency in Romania

The Natura 2000 network was created for the protection of threatened, endangered, and rare species and habitats of Europe (Maiorano et al., 2007), especially of Eastern European countries (Bladt et al., 2009). Iojă et al., (2010) analyzed the Romanian Natura 2000 extent and concluded that, in the case of plants, the spatial coverage is less than optimal. This conclusion of Iojă et al., (2010) is supported by our study in that Natura 2000 provides low percentage of protection (33.76%) of the total potential distribution of *L. sibirica* in Romania (Table 5). In time, this low, probably inefficient coverage may result in loss of genetic variability of the *L. sibirica* insular populations. In the global warming context, there are no significant differences between the present and 2080 (A2a and A2b) models. We can thus conclude that *L. sibirica* will not be affected by global warming since its niche is conserved.

Taking into account the low coverage of the present and future bioclimatic niche of *L. sibirica* under the Natura 2000 network in Romania and previously published results (Iojă et al., 2010), we recommend that information provided through species distribution models (both present and future) in relation to climatic change scenarios should be considered for improving protected area networks.

4.2. Major conservation concerns of *L. sibirica*

Wetlands, and especially mires, either oligotrophic or eutrophic, played an important role as refuge during the ice age dry phases and conserved a high number of relict species in disjunct areas (Hájek et al., 2010). Unlike boreal and arctic zones, many wetlands from central and southern Europe have been modified by human activity, mires being one of the most threatened ecosystems in the temperate zone of Europe (Hájek et al., 2010).

The warming climate led to the restriction of this areal toward the swampy areas of Europe, especially in the mountain regions. In the Carpathian Mountains most of *L. sibirica* populations are located in all the major subdivisions, i.e. Eastern, Western, and Southern Carpathians. In the Eastern Carpathians the species is most abundant especially in the western depressions and less in the eastern region which has a continental climate. Also, the number of identified populations is lower in the southern Transylvanian Alps. This can be explained by the shape and massiveness of the Carpathians, which are opened to West. Those characteristics favour an intensification of precipitation on the western and northern slopes, unlike the eastern ones (Săraru, 2008).

On the European scale, in any part of its distribution range, *L. sibirica* seems to face a common threat: habitat reduction (destruction). The majority of populations are threatened by human activities, even though they are protected (Kukk, 2003b). Also, habitat destruction is taking place at a faster pace than the establishment of the Natura 2000 sites (Hájek et al., 2010). Conservation planning is further complicated by presence of many types of mires in areas of touristic interest, close to main roads or to human communities (Hájek et al., 2010).

Another important issue is the lack of information on the status of the European populations. For example, in Romania the geographic range of *L. sibirica* is relatively well known, but information about the population size or structure is poor (Sârbu et al., 2007).

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