Predictive distribution modeling for *Eranthis hyemalis* (*Ranunculaceae*) – a species of special conservation interest in Bosnia and Herzegovina

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Abstract. *Eranthis hyemalis* occurs in the temperate region of South Europe and the Balkans. Due to its limited distribution and small population sizes, its conservation status varies. Based on 16 georeferenced localities from Bosnia and Herzegovina and 19 bioclimatic variables extracted from the WorldClim dataset, a species distribution model for the area of Western Balkans is produced in MaxEnt. The highest score of relative contribution to the MaxEnt model goes to precipitation seasonality (57,7%), mean diurnal temperature range (17,2%) and isothermality (8,6%). The model predicts that the most suitable area for Winter Aconite lies in NW and Central Bosnia and Herzegovina and E Serbia, which corresponds to the recently published data for Serbia.

Key words: bioclimatic factors, conservation status, MaxEnt, QGIS, Winter Aconite

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Introduction

Winter Aconite or *Eranthis hyemalis* (L.) Salisb. (*Ranunculaceae*) is an early spring ephemeral occurring in the mountain ecosystems of the Northern Hemisphere (Ziman & Keener 1989). It is native to South Europe, including France, Italy and the Balkans, as far as Turkey. It is also naturalized in Britain (Boens 2014) and North America (Parfitt 1997). The plant inhabits humid environments of the deciduous

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forests in temperate Europe (Xiang & al. 2021). Šilić (1990) has emphasized that in Bosnia and Herzegovina (B&H) it grows along the shrub edges in oak-hornbeam forests (*Querco-Carpinetum betuli*), vineyards, orchards and arable lands (Fig. 1).

However, along with the hygric and mesic habitats in NW Bosnia and Herzegovina, Brujić & al. (2006) have also described xerothermic ones. There are several confirmed localities in Serbia, with the most numerous population found within stands of *Robinia pseudoacacia* surrounded by arable land (Petrović & Lakušić 2017). Similar habitat description is given for Croatia, where in degraded *Carpino betuli-Quercetum roboris* and *Querco-Carpinetum illyricum* communities a population with the highest abundance has been found within the young stands of *R. pseudoacacia* (Topić & Šegulja 1983; Franjić 1992, 1997; Nikolić 2020). In Poland, the most numerous population has been found in the riparian slope-type forests on moraine (Czarna & al. 2009).

Fig. 1. Population of Winter Aconite in an orchard at Donja Gračanica (Photo: E. Sarač-Mehić, February 2022).

The conservation status of the species differs between countries. It has been considered Rare in Slovenia, Croatia and Hungary, whereas in Romania it is in the Data Deficient (DD) category (Budak 1999). In the late 1990s, it was categorized as Extinct (EX) in Bosnia and Herzegovina (Šilić 1992-1995), a category soon dismissed after the species has been found in several new localities (Brujić & al. 2006; Milanović & al. 2011). Presently, this species is considered Critically Endangered (CR) in Bosnia and Herzegovina, Serbia and Bulgaria (Budak 1999; Brujić & al. 2006; Đug & al. 2013; Bogosavljević & Zlatković 2018). In Italy, this taxon is regionally Endangered (EN) (Budak 1999). For the purposes of investigation, it should be emphasized that the center of its area is on the territory of Bosnia and Herzegovina (Brujić & al. 2006). The aim of the present study is: i) to define the ecological variables which contribute to its distribution; ii) to predict the potential distribution of *E. hyemalis* in Bosnia and Herzegovina based on these findings; iii) to find out if there is a need for reassessment of its conservation status in Bosnia and Herzegovina.

Material and methods

Georeferenced data for 16 localities in Bosnia and Herzegovina, taken from literature (Beck Mannagetta 1903-1927; Brujić & al. 2006) or recorded in personal communications with field botanists (Šarić 2021; Velić 2021; Sarač-Mehić 2022), were imported in QGIS ver. 3.4 (Fig. 2) and processed in MaxEnt ver. 3.4.1. (Phillips & al. 2019). MaxEnt is a self-contained Java application for species distribution modelling (SDM) based on occurrence records, along with environmental variables. It predicts the species distribution with high accuracy

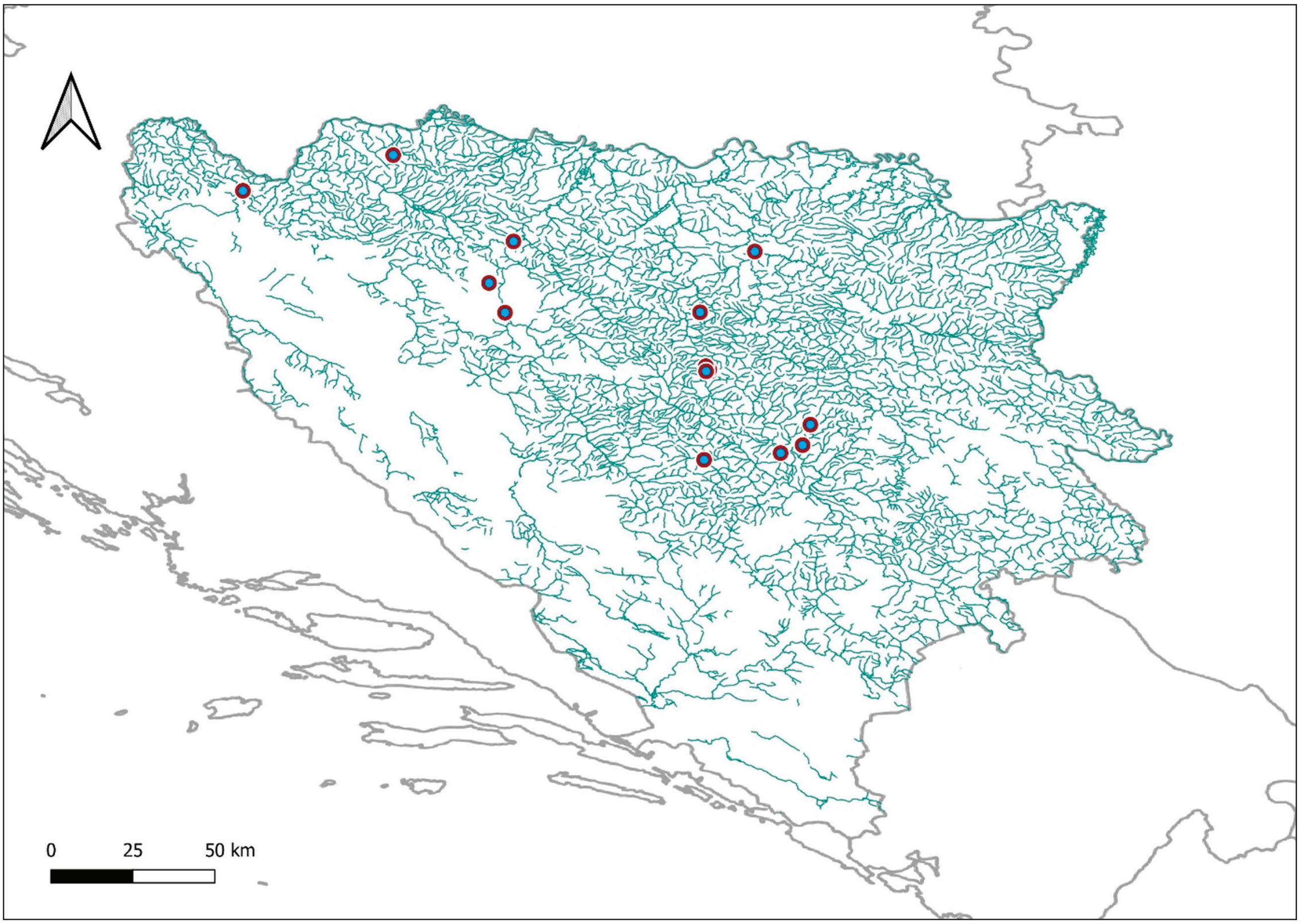

Fig. 2. Analyzed localities of Winter Aconite in Bosnia and Herzegovina in relation to hydrological network (several localities in Central Bosnia and Herzegovina overlap due to proximity).

based on small sample sizes (Phillips & al. 2006). For that purpose, 19 bioclimatic factors of the WorldClim dataset have been extracted and at the resolution of 30 arc seconds have been downloaded from the WorldClim webpage. The variables were: bio1 – annual average temperature; bio2 – amplitude of daily average temperature; bio3 – (bio1/bio7) * 100; bio4 – standard deviation of temperatures; bio5 – maximum temperature of the warmest month; bio6 – minimum temperature of the coldest month; bio7 – annual temperature amplitude (bio5 – bio6); bio8 – average temperature of the wettest year quarter; bio9 – average temperature of the driest year quarter; bio 10 – average temperature of the warmest year quarter; bio11 – average temperature of the coldest year quarter, bio 12 – annual precipitation amount; bio13 – precipitation amount of the wettest month; bio14 – precipitation amount of the driest month; bio15 – precipitation variation coefficient; bio16 – precipitation amount in the wettest year quarte; bio17 – precipitation amount in the driest year quarter; bio18 – precipitation amount in the warmest year quarter; and bio19 – precipitation amount in the coldest year quarter. To run the models, options of maximum 500 iterations, logistic output format and cross-validation with three replications have been selected. In order to refine the distribution model, additional variables (River/Stream distance) and spatial analysis have been used, with hydrological network and satellite images.

Results and discussion

The SDM output in MaxEnt for *E. hyemalis* refers to a wider area of the Western Balkans, with an ecological optimum in the NW and central section

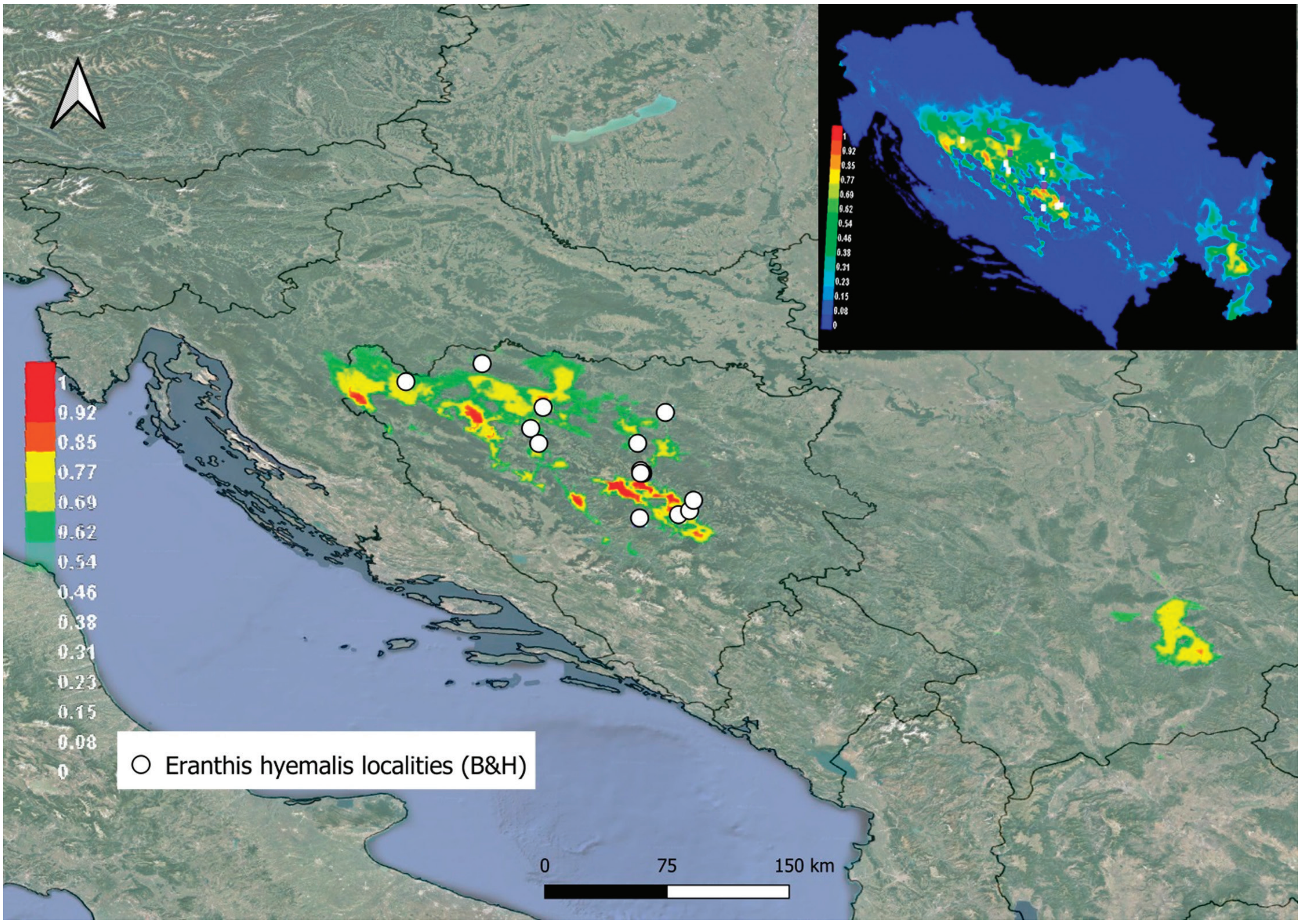

Fig. 3. MaxEnt model showing > 0.54 for Winter Aconite in the region (original output in blue).

of Bosnia and Herzegovina. Nevertheless, the model indicates a high probability (>0.54) for *E. hyemalis* to occur in E Serbia (Fig. 3), which is confirmed by some recently discovered new localities at Vrška Čuka in Serbia (Petrović & Lakušić 2017).

However, the population of Winter Aconite at peak Vraška Čuka (on the border betwen Bulgaria and Serbia) was subsequently identified as *E.bulgarica* Stef. (Vladimirov 2009, 2015), which grows on karst and lithosol, in the xerothermal belt of oak forests (Erst & al. 2020). This description corresponded to the two habitats (at Greben Grad and Brenica) described by Brujić & al. (2006) in the canyon of river Vrbas in Bosnia and Herzegovina. Of the analyzed bioclimatic variables in MaxEnt (Fig. 4), the most significant ones turned out to be precipitation seasonality (57,7%), mean diurnal range (17,2%) and isothermality (8,6%).

According to MaxEnt score >0.54, the distribution area of Winter Aconite in Bosnia and Herzegovina is 10849.9 km^2. After overlapping the satelite images and hydrological network, a positive correlation between the River/Streams layer and the occurrence of Winter Aconite becomes evident. All localities are in a 1 km range from the river bodies. Therefore, this parameter has been applied as discriminatory in QGIS and the area of potential distribution in Bosnia and Herzegovina has been recalculated as 8654.12 km^2 (Fig. 5).

Mention deserves the fact that SDM indicates occurence of suitable habitats for Winter Aconite in the watershed of Mutnica, Korana and Glina rivers, in the most prominent NW section of Bosnia and Herzegovina, where it has not been recorded yet. However, its easternmost populations are predicted to occur in Central Bosnia and Herzegovina, which corresponds

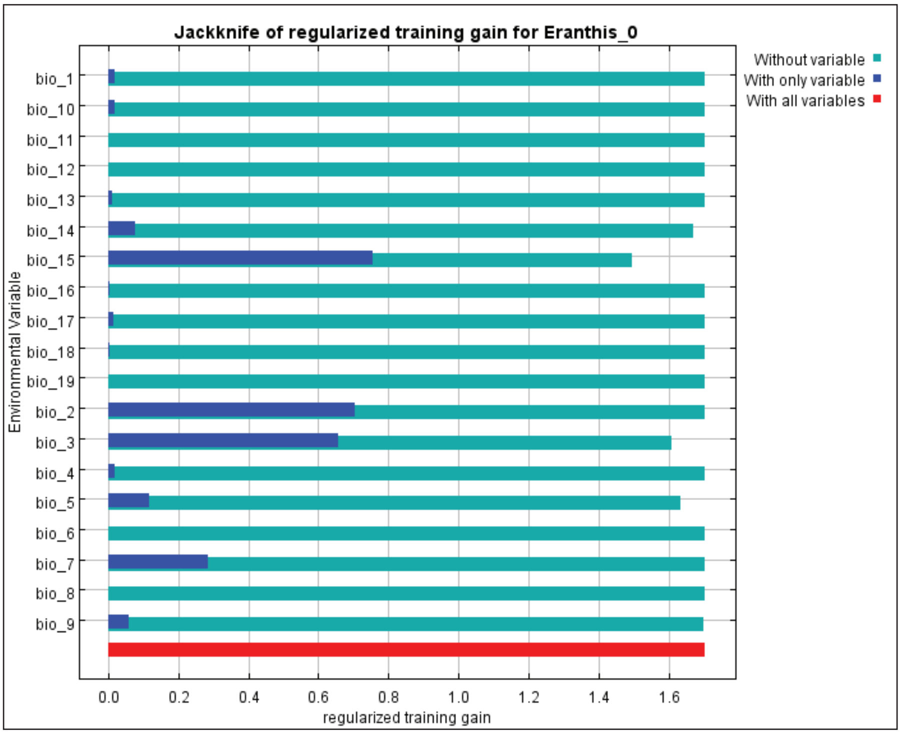

Fig. 4. Jackknife training gain for evaluation of the relative importance of bioclimatic variables for the potential distribution of Winter Aconite.

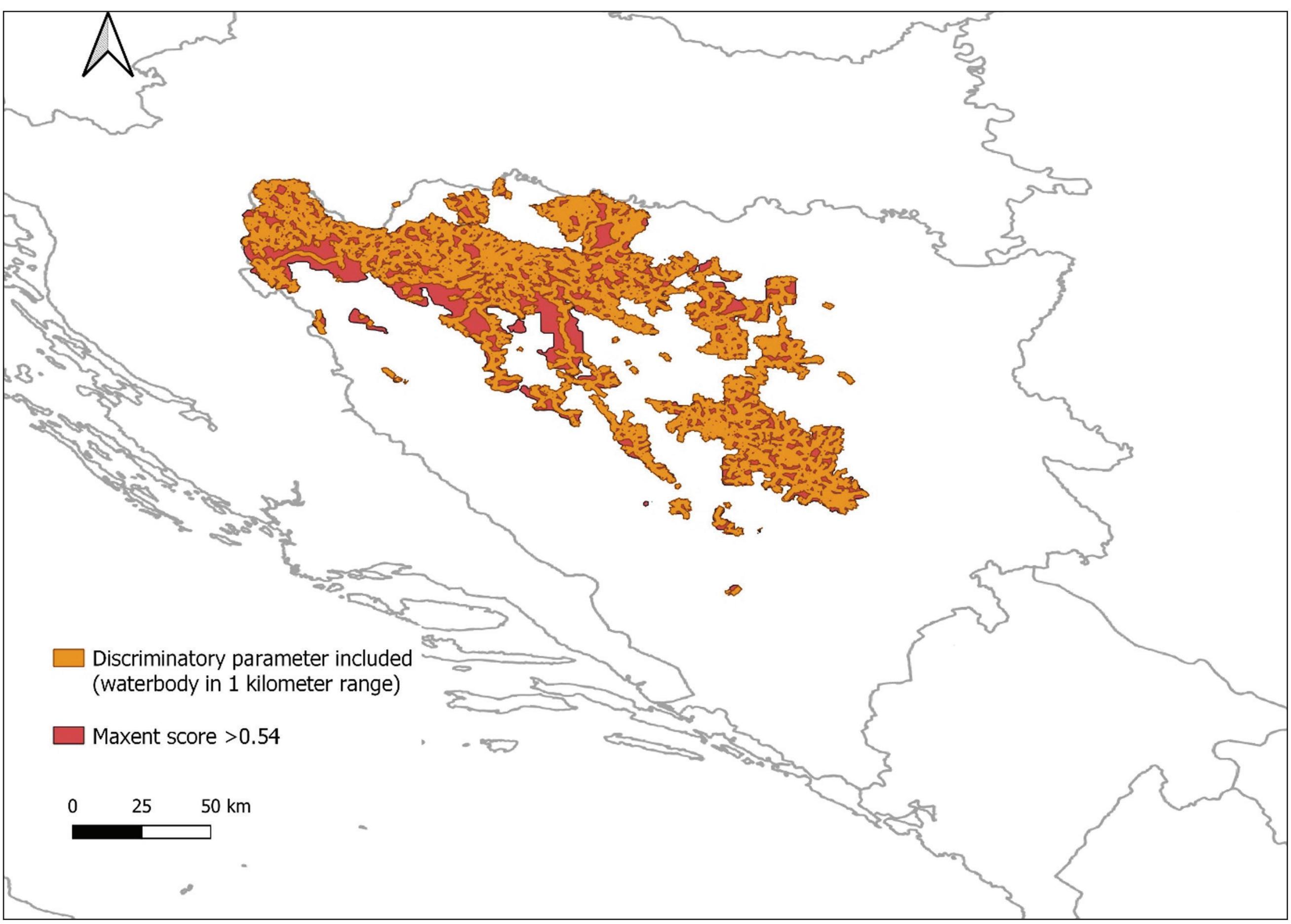

Fig. 5. Predicted SDM for Winter Aconite in Bosnia and Herzegovina.

to the transitional Illyrio-Moesian region of Bosnia and Herzegovina (Stefanović & al. 1983), which differs from the SDM indicated area in the precipitation pattern. Moreover, the observed relation of Winter Aconite populations to the river valleys could be explained by hydrochory, flood disturbances or gradient of water and nutrient supply (Burkart 1995), which is the case of the so-called river corridor plants (Burkart 2001). Furthermore, Winter Aconite propagates by seeds that germinate shortly after getting released from the follicules under adequate moist soil conditions (Rysiak & Żuraw 2011) and temperature; its dormancy ends at +4 °C (Tipirdamaz & Gömürgen 2000). For river corridor plants, interspecific interaction with mycorrhizal fungi (Nobis & al. 2015) or with animals (Hensgen & al. 2011) has also shown certain significance. Some findings suggest that the nutrient gradient might be crucial (Nobis & al. 2022), whereby some distinct nutrient and water supply patterns may have been created by the urbanization process (Nobis & Skórka 2016). Thus, many regionally native species have increased their range through human mediation and their ability to survive in anthropogenic landscapes (Lôbo & al. 2011). Biotic homogenization has become a common outcome of land-use intensification and human interference (Lôbo & al. 2011; Gossner & al. 2016). Accordingly, in terms of urbanization along the river valleys in Bosnia and Herzegovina, it could be anticipated that human activities in the past have contributed to the dispersal of Winter Aconite. It has been cultivated and widely naturalized since 1570 (Brujić & al. 2006; Rysiak & Żuraw 2011) through its easy reproduction by tubers (Marcinkowski 2002). However, conversion of habitats, mainly by infrastructure development, has led to habitat fragmentation. According to field reports (pers. comm. of Mr. Šarić Š.), some populations in Bosnia and Herzegovina have been lost over the last year due to construction work around Zenica city. It should be emphasized that the ancestral populations of *Eranthis* migrated to the lowlands during the Eocene (Xiang & al. 2021) and were maintained in regions with suitable climate conditions. However, the poor dispersal abilities of the genus have restricted its species to distinct biogeographic regions (Wang & al. 2016).

According to the authors' findings, the extent of occurrence (EOO) and the area of occupancy (AOO), which are basic criteria for the Critically Endangered, Endangered and Vulnerable species (IUCN 2012) of Winter Aconite in Bosnia and Herzegovina, are wider than initially anticipated. Therefore, it is imperative to conduct further field studies in the areas outlined by SDM in early spring, and to reassess the species' conservation status in Bosnia and Herzegovina based on these findings.

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