RESEARCH ARTICLE

Spatial analysis and distribution modeling of *Aconitum moldavicum* in Ukrainian Carpathians and adjacent territories with special reference to the algorithm used

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Abstract

The paper aimed to conduct a comprehensive analysis of all available sources (including herbarium vouchers, publications, and datasets) on the exact distribution of *Aconitum moldavicum* in the Ukrainian Carpathians to build the maps modeling the species distribution in this region and adjacent territories.

Aconitum moldavicum is a Pancarpathian subendemic distributed widely along the Carpathian Mountain range and scattered out to some of the adjacent lowland territories. Surprisingly, *A. moldavicum* was found to be quite rare for the Transcarpathian Lowland, where it is represented only by *A. moldavicum* subsp. *hosteanum*. Just near the border with Slovakia, *A. moldavicum* subsp. *moldavicum* occurs in the Vygorlat Mts., while along with all other parts of the Vygorlat-Gutyn Carpathians it does not appear. However, both taxa, *A. moldavicum* subsp. *moldavicum* and *A. moldavicum* subsp. *hosteanum*, quite frequently appear in the Ciscarpathia and Volhynia-Podilia Highland together with their hybrid *A. moldavicum* nothosubsp. *confusum*.

Aconitum moldavicum nothosubsp. *porcii* and nothosubsp. *simonkaianum* occur exclusively in the Marmarosh region of the Ukrainian Carpathians, and probably *A. moldavicum* nothosubsp. *porcii* can also be re-find in the Chornohora. Presence of *A. moldavicum* nothosubsp. *simonkaianum* in the Volhynia-Podilia Highland seems to be doubtful because there are no other pieces of evidence despite the only voucher hosted at GJO herbarium. Moreover, other vouchers collected by B. Błocki from the same region were identified as belonging to *A. moldavicum* nothosubsp. *hosteanum*.

We used different algorithms of SDM (MaXent, BioClim, GARP, EnvDist, TIN, and IDW) to check the most sufficient and most closely representing a real distribution of *A. moldavicum* in the area studied. BioClim correctly pointed to the geographic centers of the species in the Carpathians, Volhynia-Podilia Highland, and in Polish Uplands. Traditionally applied algorithm MaxEnt underestimates the probability of occurrence of species in the area of confirmed presence and, at the same time, overestimates it in the area beyond the known extent of species occurrence. IDW algorithm showed similar results with MaxEnt and confirmed its potential suitability for SDM purposes.

Introduction

Aconitum moldavicum Hacq. is a Pancarpathian subendemic (Novikoff & Hurdu, 2015; Kliment et al., 2016) and mountain species scattering out to adjacent lowlands (Zapałowicz, 1908; Mitka & Kozioł, 2009; Misiak, 2016). *A. moldavicum* sometimes is mentioned in red lists and assessments with different threat categories (Kricsfalusy & Budnikov, 2003; Kadlečík, 2014; Cwener et al., 2016; Kozurak et al., 2017). However, it is not listed in the recent edition of IUCN Red List of Threatened Species due to the general lack of data on its taxonomy and chorology.

Aconitum moldavicum comprises five subspecies – subsp. *moldavicum*, subsp. *hosteanum* (Schur) Graebn. et P. Graebn., nothosubsp. *simonkaianum* (Gáyer) Starmühl., nothosubsp. *porcii* Starmühl., and nothosubsp. *confusum* (Grinț.) A. Novikov (Mitka, 2008; Novikov, 2017). The closest taxa revealing similar morphology and genetics are A. *lasiostomum* Besser and A. *lycoctonum* L. (including A. *vulparia* Spreng. and A. *lasianthum* (Rchb.) Simonk.) that also occur in adjacent to Carpathian Mts. regions (Utelli et al., 1999, 2000; Hong et al., 2017). They additionally contribute to the diversity of *moldavicum* group in the Carpathian region by producing putative hybrids (A. × *triste* (Rchb.) Gáyer and A. × *baumgartenianum* Simonk.) associated predominantly with Transilvania and South-Eastern Carpathians.

All five subspecies of A. *moldavicum* were already reported for the Ukrainian Carpathians and adjacent Volhynia-Podillya Highland (Novikoff & Mitka, 2011; Mitka, 2008). However, precise mapping, which is crucial for accurate assessment of species distribution and further identification of threat category, was not performed before. Spatial analysis with modern species distribution modeling (SDM) algorithms, which also can be useful for evaluation of the general distribution of the species, was not realized too. Hence, here we represent our outcomes based on an analysis of 782 collection localities gathered from field surveys, herbarium collections, and published sources.

Material and methods

Spatial data was gathered from several sources, including 563 entries from direct analysis of herbarium vouchers, 130 entries from trusted published sources (Klimuk et al., 2006; Mitka, 2008), 75 entries from Karel Domin's Card Index hosted at the Institute of Botany in Bratislava, 14 entries from GBIF biodiversity database (GBIF, 2019), JACQ virtual herbarium (JACQ, 2019) and NHM DataPortal (Scott & Smith, 2014). Only those entries that could be clearly identified as belonging to A. *moldavicum* were accepted for analysis. In case when there was a doubt or in the case whether it was impossible to identify subspecies clearly, such entries were accepted on a specific level without designation of infraspecific implication. For those entries that had no designated coordinates, approximate coordinates with annotated precision in meters were generated based either on the closest identified location or polygonal centroid. The final dataset was processed in QGIS 3.10.1 (QGIS Development Team, 2020). In QGIS, an additional mesoregional layer (accordingly to Novikov & Hurdu (2017) with recent updates) and the DEM (Digital Elevation Model) layer were associated with this dataset.

SDM was performed independently in Maxent 3.4.1 (Philips et al., 2006; Philips & Dudik, 2008), applying online facilities of Lifemapper LmSDM (i.e., BiotaPhy web client) (Williams et al., 2017), and in QGIS 3.10.1 environment. For modeling in Maxent software, we used SRTM 90m DEM layer downloaded from CGIAR-CSI (Jarvis et al., 2008). Maxent software applies same-called unique algorithm, which is considered one of the most reliable for modeling of distribution on poorly known areas and with a small sample size (Hernandez et al., 2006, 2008). Maxent software requires precise preparation of projection layers with the same resolution and covering area, which can be difficult for inexperienced users with basic skills. For modeling in Lifemapper we used 'Worldclim 1.4, Soil, SpatialDistance' model and applied BioClim, GARP, EnvDist and MaxEnt (openModeller implementation) algorithms, which are also usually applied for rich samples (Stockwell & Peterson, 2002; Beaumont et al., 2005; Passos & Rebello, 2016). SDM in QGIS
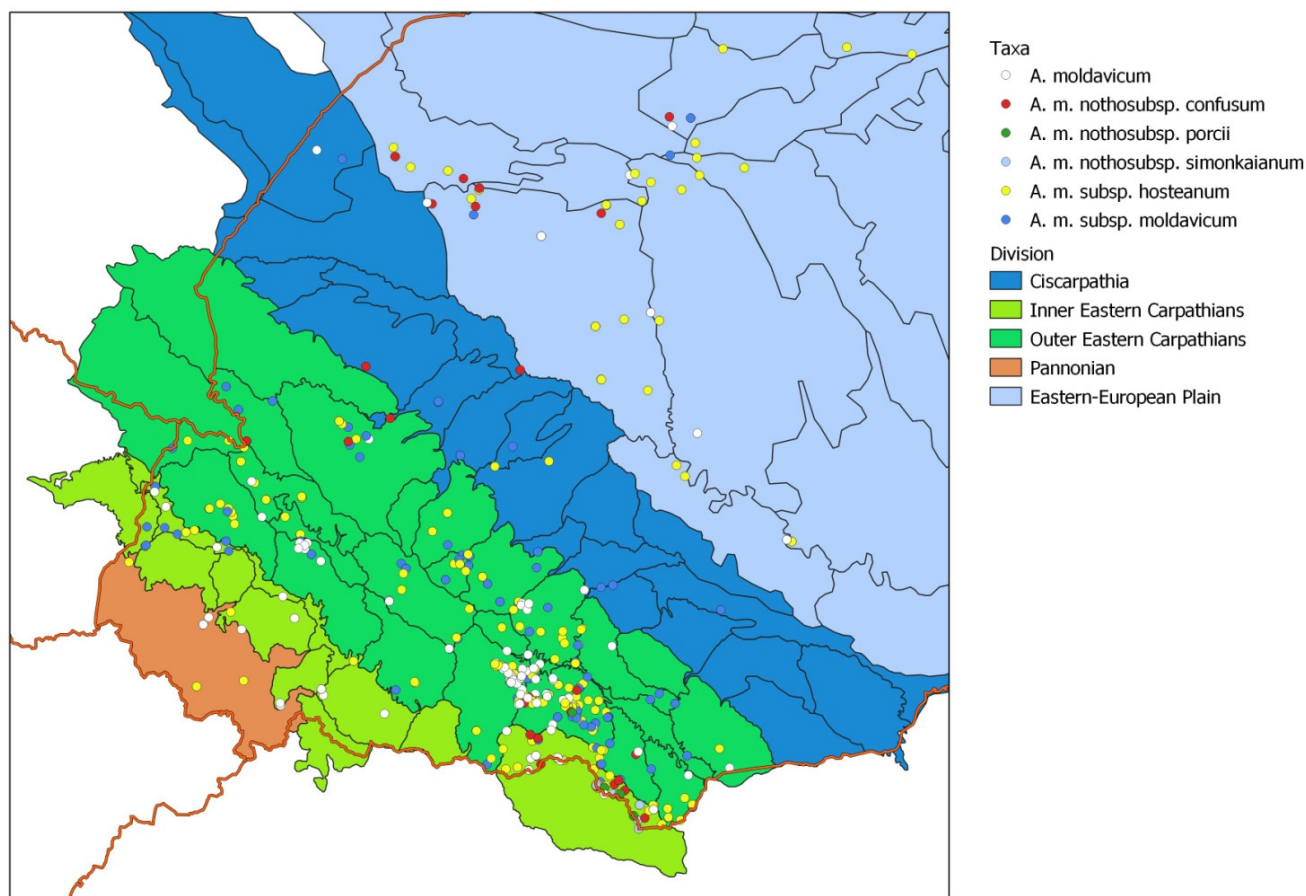
Figure 1. The original distribution of *Aconitum moldavicum* within the Ukrainian Carpathians and adjacent regions basing on all available data (field surveys, herbarium vouchers, published observations and other sources).

was performed by TIN and IDW interpolation based on a number of occurrences calculated for each geomorphologic mesoregion. TIN and IDW usually are not applied for niche modeling, because they are not prediction algorithms in a strict sense and work only with continuous data. However, it was proved that these powerful spatial interpolation methods can be useful for modeling of species richness (Tapia-Silva et al., 2015), and, as a result, can also be applied for preliminary analysis of a potential area of occupation by organisms (Gomes et al., 2018).

Results and discussion

Spatial Distribution

Our investigations revealed that A. *moldavicum* is scattered over Ukrainian Carpathians unevenly – with a higher concentration in the SE part, including Svydovets, Chornogora, and Marmarosh massifs. (Figs. 1 & 2). The number of registered occurrences of A. *moldavicum* in

subcarpathian regions (i.e., Transcarpathia and Ciscarpathia) is much lower. However, another local center of distribution of A. *moldavicum* is located in the Opillia Highland, a mesoregion of the Volhynia-Podilia Highland, situated on NE from the Carpathian ridge. The presence of a high number of occurrences in these regions correlates with subspecific diversity. In particular, the Marmarosh Mts. host all five subspecies of A. *moldavicum*, while the Chornohora Mts. and the Opillia Highland represents four and three subspecies, respectively.

Chornohora and Marmarosh are the only regions with confirmed presence of A. *moldavicum* nothosubsp. *porcii*. Most of the occurrences of this subspecies lie within Marmarosh mesoregion, and only one voucher from 1926 is cited for Chornohora.

Another hybrid, A. *moldavicum* nothosubsp. *simonkaianum* occurs only in the Marmarosh Mts. (in those part that is usually mentioned in publications as the Chyvchyny Mts.). In Mitka (2008) there is mentioned voucher
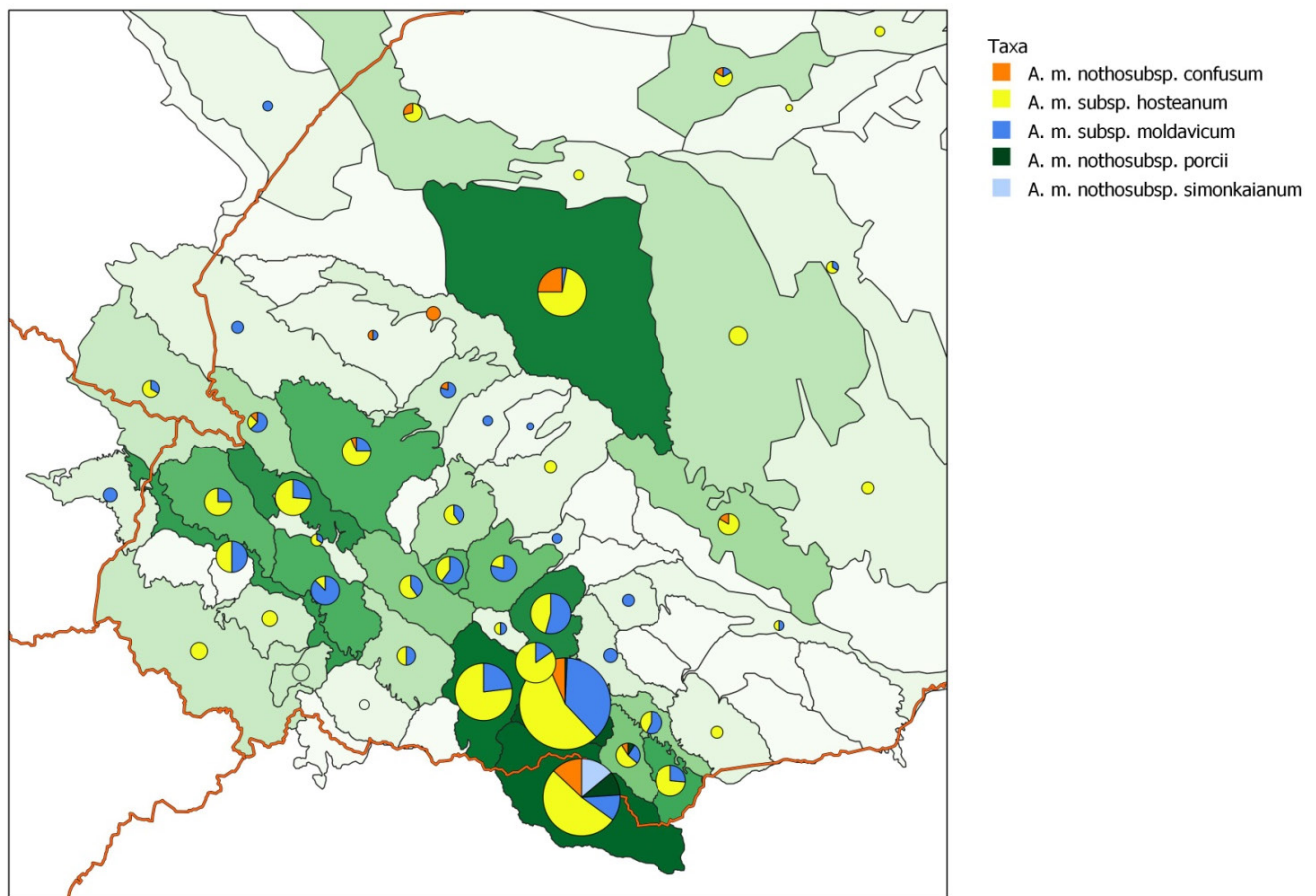
Figure 2. Proportional distribution of *Aconitum moldavicum* within the Ukrainian Carpathians and adjacent regions (the darkest color of mesoregion, the higher number of observations).

of A. *moldavicum* nothosubsp. *simonkaianum* preserved in the herbarium GJO of Universalmuseum Joanneum in Graz, Austria. However, after analysis of other vouchers collected by the same collector (B. Błocki) from the same region and at the same period, we could suggest that it likely belongs to A. *moldavicum* nothosubsp. *hosteanum* that is quite frequent in the Volhynia-Podilia Highland.

One of the parental taxa of A. *moldavicum* nothosubsp. *simonkaianum* is A. *lasiostomum* (= A. *rogowiczii* Wissjul.), which mostly occurs in the Steppe and Forest-Steppe regions of Ukraine (Dobrochaeva et al., 1987; Tzvelev, 2001). However, one locality of A. *lasiostomum* is cited from the Opillia Highland (between villages Ivanivka and Podusilna, Lviv region) and one more locality of A. *rogowiczii* from the Holohory (Kremenets town, Ternopil region) (Wissjulina, 1953). Hence, we cannot reject the possibility of the presence of A. *moldavicum* nothosubsp. *simonkaianum* in the Volhynia-Podilia Highland, at least in the past.

Aconitum *moldavicum* nothosubsp. *confusum*, resulting from hybridization between subsp. *moldavicum* and subsp. *hosteanum*, also shares the same distribution with A. *moldavicum* nothosubsp. *hosteanum*, including the Volhynia-Podilia Highland and the Poland Uplands. Interesting that participation of A. *moldavicum* nothosubsp. *confusum* in the Opillia Highland and neighboring regions is relatively high (about 25 %), while in separated mesoregions of the Carpathian Mts. it does not exceed 13 %. Hence its presence reveals that either parental taxa still could be discovered in this region or they were distributed there before. In general, A. *moldavicum* subsp. *moldavicum* and A. *moldavicum* subsp. *hosteanum* remain to dominate both in the Carpathians and adjacent lowlands.

Both hybrids, A. *moldavicum* nothosubsp. *simonkaianum* and A. *moldavicum* nothosubsp. *porcii*, demonstrate distribution pattern slightly different from all other subspecies of A. *moldavicum*. Most occurrences of these two endemic taxa (Mitka, 2008) are

concentrated in the Marmarosh Mts. region, which is considered one of the local centers of endemics' distribution in the Ukrainian Carpathians (Tasenkevich, 2014) within the main Pokuttya-Marmarosh center of endemism (Pawłowski, 1970).

The Svydovets, Chornogora, and Marmarosh Mts. are among the highest regions of the Ukrainian Carpathians and differ by the highest diversity of flora (Chopyk, 1976; Malynovskiy, 1991; Tasenkevich, 2003). In particular, Chornogora represents the highest diversity of genus *Aconitum* in the Ukrainian Carpathians (Novikoff et al., 2016). However, A. *moldavicum* is not related to high altitudes so much. In the Ukrainian Carpathians, it mostly occupies localities from submontane to upper montane belt (roughly 650–1400 m a.s.l.). Sometimes it occurs in the subalpine belt (up to 1850 m a.s.l.), and only occasionally can be found in the alpine belt. Therefore its correlation with high-altitudinal mesoregions has rather an inexplicable nature.

Surprisingly, A. *moldavicum* is quite rare for the Transcarpathian Lowland and adjacent regions of the Carpathian range. Here it seems to be represented only by A. *moldavicum* subsp. *hosteanum*. Just near the border with Slovakia, A. *moldavicum* subsp. *moldavicum* occurs in the Vygorlat Mts., while along with all other parts of the Vygorlat-Gutyn Carpathians it does not appear.

Aconitum moldavicum prefers wet and semi-shaded locations, especially often it is distributed in the forests along the streams that make natural corridors of its propagation (Mitka, 2003; Novikoff et al., 2016). However, it also can be found in relatively dry and open places, where it differs by short and compact shoot, lower number of flowers, and slightly branched inflorescences. The plant demonstrates the widest ecological amplitude and very often can be found in semiruderal and disturbed places along the roads, in mountain villages, in forest fringes, etc. However, local populations of A. *moldavicum* are usually small and represented by few clone plants that appeared in the result of rhizome fragmentation. Seed propagation in A. *moldavicum* has not been investigated yet, but our preliminary conclusion is that it plays a secondary role.

In the Ukrainian Carpathians A. *moldavicum* can be often found in very different habitats including vegetation communities of lower elevations like *Fagion sylvaticae*, *Tilio-Carpinetum*, *Dentario glandulosae-Fagetum*, *Alnetum incanae*, *Rubetum idaei* and *Scirpo sylvatici-Caricetum brizoidis*, as well as communities of higher altitudes like *Chaerophylletum aromaticum*, *Stellario nemorum-Alnetum glutinosae*, *Pulmonario-Alnetum viridis*, *Juniperetum sibiricae*, *Calthetum laetae*, *Arunco-Doronicetum austriaci* and *Ranunculo platanifolii-Adenostyletum alliariae* (Mitka & Kozioł, 2009; Novikoff et al., 2016; Kobiv, 2018). Both subspecies, A. *moldavicum* subsp. *moldavicum* and A. *moldavicum* subsp. *hosteanum* share the same ecological and vegetation conditions and even can be found in mixed populations together with A. *moldavicum* nothosubsp. *confusum*. However, the preferences of A. *moldavicum* nothosubsp. *simonkaianum* and A. *moldavicum* nothosubsp. *porcii* require clarification. Investigations on *Aconitum* habitat preferences, including soil and vegetation analysis, were carried out before (Novikoff et al., 2016; Novikoff, 2016), but still seek information from a more full area.

Species distribution modeling

Firstly we applied the single elevation parameter for SDM in original Maxent software to stress it as a critical factor for the distribution of A. *moldavicum*. This was done to eliminate side-effecting factors and to reveal any potential influence of the elevation on the distribution of this species. The elevation is frequently reported as one of the key factors, affecting the distribution of plant taxa, especial endemic, in different mountain regions (Vetaas & Grytnes, 2002; Wang et al., 2003; Singh et al., 2007; Subedi et al., 2015), including Carpathian Mountains (Tsaryk et al., 2003; Piękoś-Mirkowa & Mirek, 2009; Kyyak et al., 2016; Mráz et al., 2016). In particular, elevation has confirmed influence on the origination of genetic diversity and speciation in mountain plants (Thiel-Egenter et al., 2009), including *Aconitum* representatives (Hardin, 1964; Sutkowska et al., 2013; Chapagain et al., 2019). In our preliminary investigations, we have also suggested that elevation may be the factor determining the structure of the inflorescence in A. *variegatum* L. (Novikoff, 2009). Similarly, it was found that elevation in the context of

climate changes influences on the phenology of A. *heterophyllum* Wall. (Gaira et al., 2011). Hence, here we tried to separate elevation from other factors to analyze its influence on the distribution patterns of A. *moldavicum* independently. Later additional algorithms (i.e., BioClim) covering other factors were also applied within Lifemapper online service to obtain more complete results.

We generated maps of the prospective distribution of A. *moldavicum* basing on four datasets: (A) all available occurrence data; (B) data just about precise occurrence (only from mountain regions); (C) combination of precise localities from mountains with estimated localities from lowlands; (D) estimated localities from lowlands only (Fig. 3 A–D). In a case of the full dataset, the main distribution was concentrated in the regions with the highest altitude. In contrast, in the lowlands, the prognostic distribution does not exceed 23 % (with relatively low AUC = 0.797). Chornohora, Svydovets, and Gorgany regions, at the same time, are among the highest and very popular for floristic surveys. Moreover, many coordinates were obtained from approximate supposition and could point to higher localities than they are. To avoid artificial amplification of high-mountain regions, we analyzed localities with only precisely known coordinates and elevation respectively. In this case, high-mountain regions were still modeled as the most appropriate for the distribution of A. *moldavicum*, while lowlands were illuminated from analysis and demonstrated prognostic distribution below 8 %. AUC value in such a case was 0.919, which confirms the high reliability of obtained prediction (Jiménez-Valverde, 2012). Finally, we combined an almost equal number of localities with precise coordinates with those with approximate coordinates, and still, the highest regions remained to be the most suitable. As a result of such a combination, the lowland regions obtained up to 54 % of prediction; however, the AUC value was the lowest – 0.713. As a result of the analysis, the dataset of exclusively approximate localities from lowlands, mountains were totally omitted but predicted distribution on lowlands did not oversize 77 % with relatively low accuracy (AUC = 0.766).

Relatively low accuracy of obtained models in case of analysis of (C) and (D)

datasets together with high accuracy obtained during analysis of dataset (B) (Fig. 3) indicate that altitude is not a key factor for the distribution of A. *moldavicum* in lowland regions. Nevertheless, still, elevation seems to be among essential factors affecting the distribution of A. *moldavicum* in the mountain region of the Ukrainian Carpathians.

In lowlands, the elevation changes not so dramatically as in the mountains. In the mountains, the elevation changes are much frequent and therefore require more precise identification of coordinates. The application of data with approximately estimated coordinates in the mountains could be risky. However, our analysis showed almost consistent results both for precise data and the combination of precise and approximate data. Hence we can assume that such mixed datasets can be effectively applied for SDM. From another side, data cleaning before analysis is a necessary process that should be conducted by specialists that are familiar with ecological preferences of analyzed taxa (Maldonado et al., 2015; Gomes et al., 2018). Splitting of datasets on smaller portions also can be useful for niche modeling of taxa distribution in heterogeneous areas (Stockwell & Peterson, 2002).

Lifemapper online tool provides an excellent opportunity for modeling species distribution, including the number of layers and algorithms, as well as on-flight export of data from GBIF. We applied four main algorithms (Fig. 4) that showed utterly different results. MaxEnt prediction was close to that we obtained using original Maxent software with strong attribution to high-mountain regions of the Ukrainian Carpathians. However, lowland regions of the Volhynia-Podilia Highland obtained much higher prediction (Fig. 4 A). On a large scale, MaxEnt algorithm also showed a higher prediction of the distribution of A. *moldavicum* along all the Carpathian Mts. range and even extension of its areal to the Apuseni in Romania, the Sudety Mts. in the Czech Republic and the Austrian Alps (Fig. 5 A). Outside the Carpathians, such modeled distribution of A. *moldavicum* has only theoretical value since it is the Carpathian's subendemic. BioClim algorithm, in general, demonstrated quite a low level of 50 % prediction, evenly scattered along the Ukrainian Carpathians and covered almost all
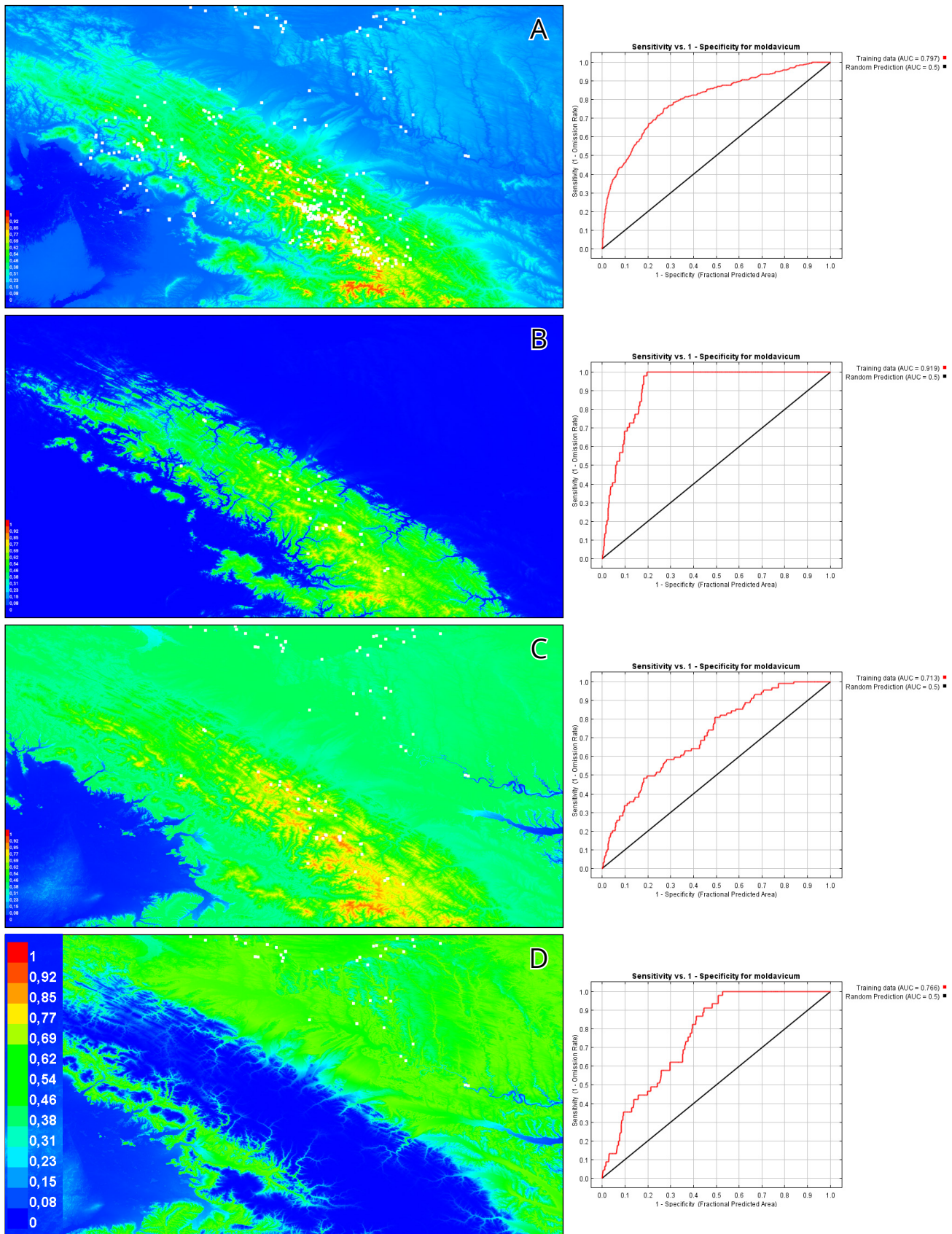
Figure 3. Maxent prediction of *Aconitum moldavicum* distribution in the Ukrainian Carpathians and adjacent regions basing from elevation. Color scale indicates occurrence prediction. Graphs show AUC values for each of the predictions (the higher AUC the highest reliability of the model obtained). Models are based on all available distribution data (**A**); exclusively precise data obtained from direct observations in mountain regions (**B**); the combination of precise localities from mountains with estimated localities from lowlands (**C**); estimated localities from lowlands only (**D**).
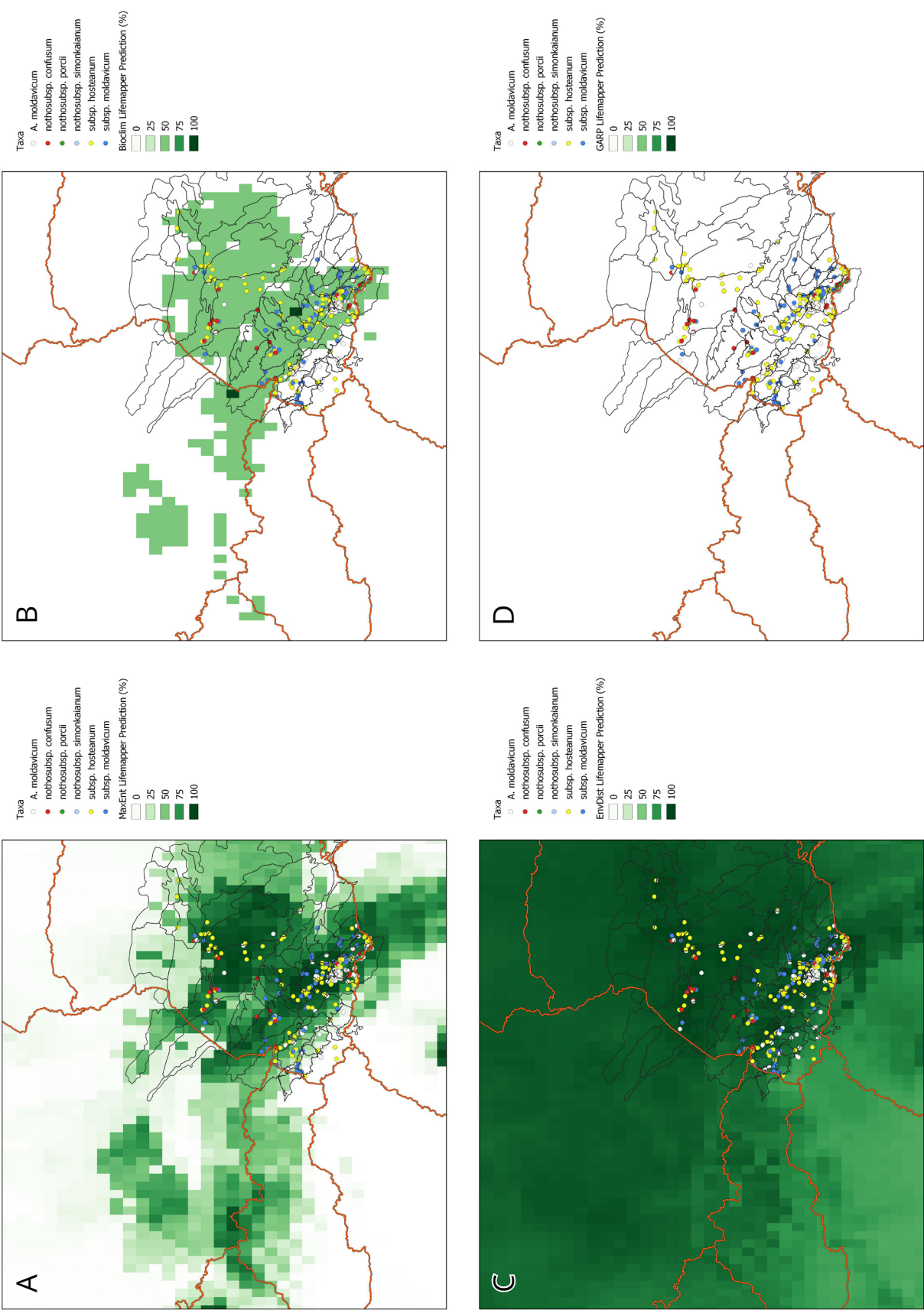
Figure 4. Lifemapper prediction of *Aconitum moldavicum* distribution in the Ukrainian Carpathians and adjacent regions basing on different algorithms applied: **A** – MaxEnt, **B** – BioClim, **C** – EnvDist, **D** – GARP. The darkest color indicates a higher prediction on the site. Points indicate known locations.
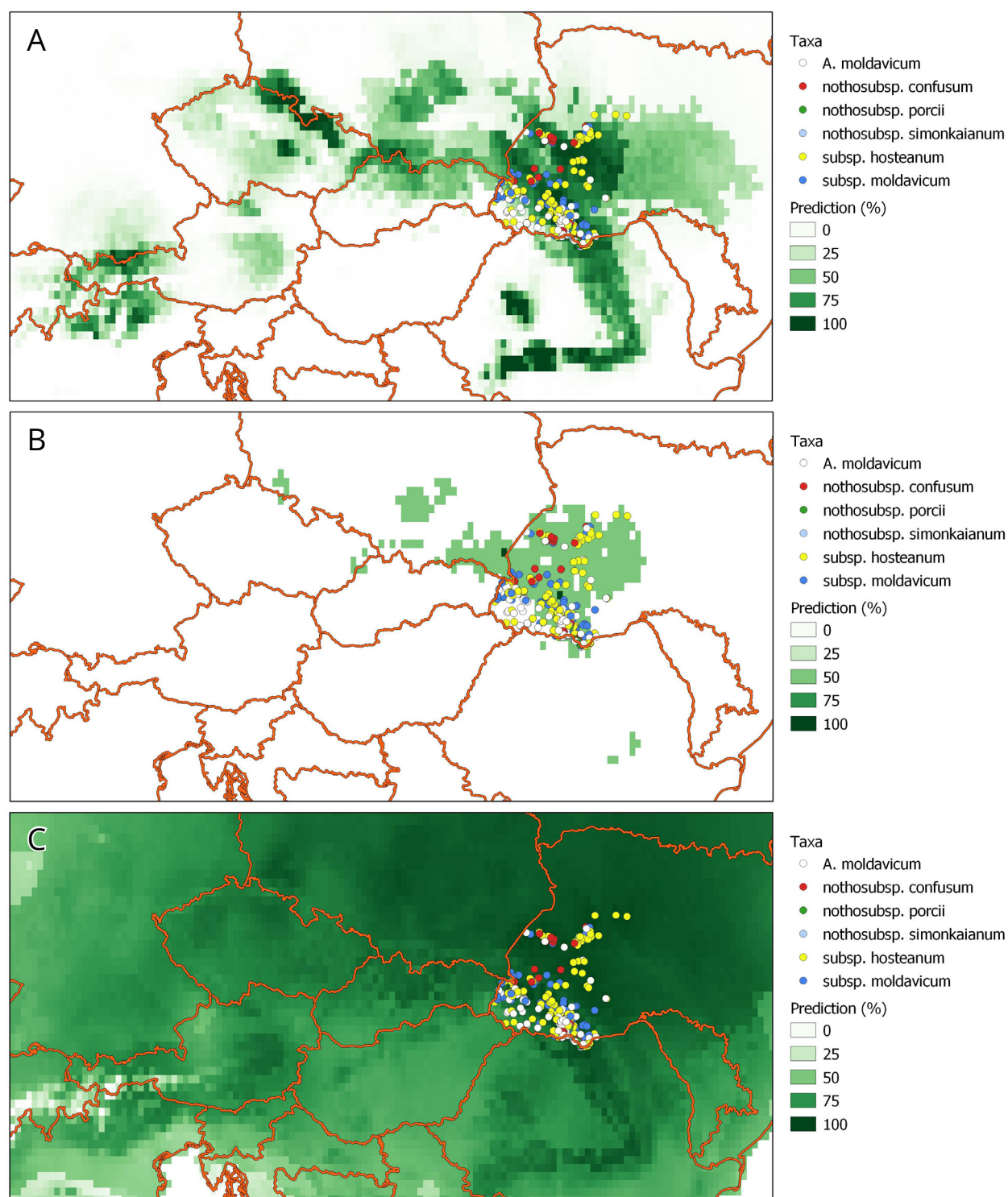
Figure 5. Lifemapper prediction of *Aconitum moldavicum* distribution within a wider range basing on different algorithms applied: **A** – MaxEnt, **B** – BioClim, **C** – EnvDist. The darkest color indicates a higher prediction on the site. Points indicate known locations within the Ukrainian Carpathians and adjacent regions.

Volhynia-Podilia Highland (Fig. 4 B). However, on a large scale, BioClim predicted distribution of A. *moldavicum* predominately in the Eastern Carpathians with scattering in the Western Carpathians, and slight distribution to the South Carpathians (Fig. 5 B). These results the closest correspond to the real disthution of A. *moldavicum*, and especially interesting is its prediction for the Polish Uplands, where is one of the local lowland centers of the species distribution (Szafer, 1930; Zając, 1996; Mitka, 2008; Mitka & Kozioł, 2009; Mitka et al., 2013).

Another two algorithms of Lifemapper, EnvDist, and GARP did not show any acceptable results. EnvDist prediction covered almost all terrestrial parts of Europe (Figs. 4 C & 5 C). Sites predicted by EnvDist also sporadically appeared in Northern America (from Alaska Range through Rocky Mts. and to Appalachian Mts.), North China Plain, Korea, Japan, and Kamchatka. GARP did not generate any prediction at all (Figs. 4 D).

Finally, for SDM we applied in-build interpolation algorithms TIN and IDW from QGIS 3 package (Fig. 6). Both TIN and IDW are factor-unrelated algorithms and predict distribution exclusively basing on a calculation of distances from extant localities. This makes them unacceptable for prediction in cases with low data coverage but still can be useful for preliminary estimation of the distribution of species, especially those with continuous ranges. Moreover, traditionally applied algorithms like MaxEnt can underestimate the probability of occurrence of species in the area of confirmed presence and, in the same time, overestimate it in the area beyond the known extent of species occurrence (Fitzpatrick et al., 2013; Gomes et al., 2018). In our case, both methods (TIN and IDW) showed the highest prediction of *A. moldavicum* in the Chornohora Mts., with slightly less concentration in surrounding mesoregions – Marmarosh, Svydovets, Gorgany and partly in Gryniava. IDW also predicted extension of *A. moldavicum* areal to the Romanian Carpathians, with the highest concentration in the Maramures and Rodna Mts. Both methods also confirmed the presence of a semi-isolated center of distribution of *A. moldavicum* in the Opillia Highland. The general similarity of obtained results from IDW and MaxEnt confirmed the suitability of IDW application for SDM purposes.

Conclusions

Taking into count all results, we can assume that the occurrence of *A. moldavicum* is not dependent on elevation in lowland regions. However, within the Carpathian Mts., it still plays an important role. Hence, further precise investigations with detailed analysis of other ecological data harvested directly

from populations are required. Nevertheless, the distribution of A. *moldavicum* in the Ukrainian Carpathians is mainly related to such highest mesoregions as Chornohora, Marmarosh, Svydovets, and Gorgany. While in the Volhynia-Podilia Highland it is mostly concentrated in the Opillia Highland; where is, probably, located its local center of the distribution.

Analyzing prediction models and known distribution, we can also confirm that A. *moldavicum* (including subsp. *moldavicum*, subsp. *hosteanum*, and nothosubsp. *confusum*) is a Pancarpathian subendemic. A. *moldavicum* nothosubsp. *simonkaianum* is an Eastern-Carpathian (sub)endemic and A. *moldavicum* nothosubsp. *porcii* is a South-Eastern Carpathian – Apuseni endemic. Both, A. *moldavicum* nothosubsp. *simonkaianum* and A. *moldavicum* nothosubsp. *porcii* have extremely limited distribution in the Ukrainian Carpathians (Marmarosh and probably Chornohora Mts.) and require protection.

IDW algorithm demonstrated good results of distribution analysis and prediction together with MaxEnt and, therefore, can be applied for in niche modeling. This is concordant with recently published results of Gomes et al. (2018). BioClim algorithm resulted in slightly different outcomes that do not allow to evaluate the level of prediction of A. *moldavicum* among different mesoregions, but the better delimited general range of the species. Hence, we believe that any of the mentioned algorithms cannot be applied separately. Only a combination of different SDM algorithms can result in appropriate modeling.
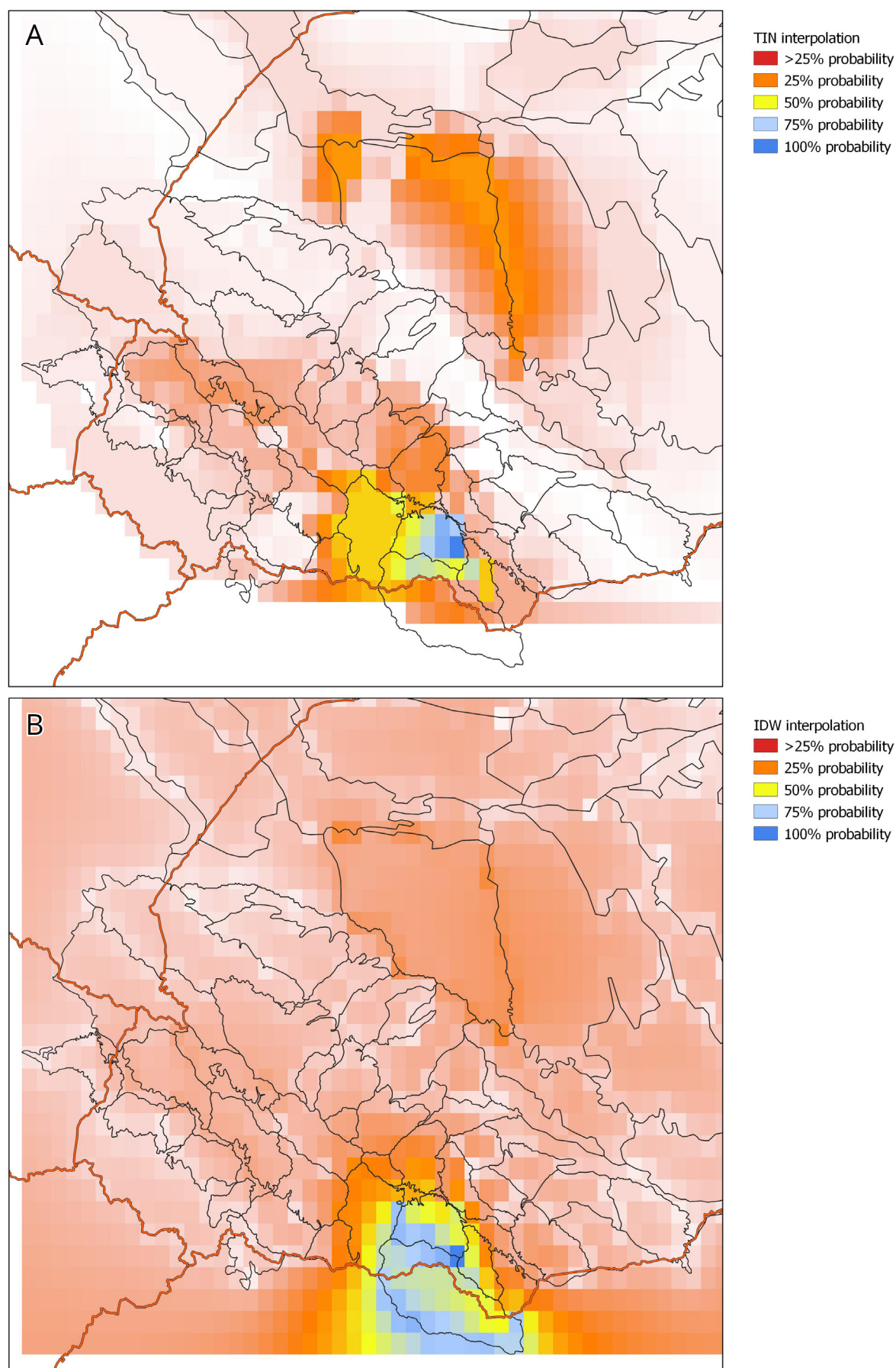
Acknowledgements

Figure 6. TIN (**A**) and IDW (**B**) interpolations applied for SDM purposes. Prediction of *Aconitum moldavicum* distribution in the Ukrainian Carpathians and adjacent regions based exclusively on known localities.

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Просторовий аналіз та моделювання поширення *Aconitum moldavicum* в Українських Карпатах та на прилеглих територіях з наголосом на використані алгоритми

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Стаття має на меті представити всебічний аналіз всіх доступних даних (включаючи гербарні збори, опубліковані відомості та бази даних) щодо поширення *Aconitum moldavicum* в Українських Карпатах з метою побудови карт, що моделюють поширення цього виду в регіоні та на прилеглих територіях.

Aconitum moldavicum – це карпатський субендемік, що широко розповсюджений по території усіх Карпат і частково виходить за межі гірського масиву на прилеглі рівнинні території. Цікаво, що *A. moldavicum* є доволі рідкісним для Закарпатської рівнини, де він спорадично представлений виключно підвидом *A. moldavicum* subsp. *hosteanum*. Цікаво також, що інший підвид, *A. moldavicum* subsp. *moldavicum*, представлений на Вигорлат-Гутинському масиві виключно на Вигорлатських горах поблизу кордону зі Словаччиною і більше ніде в межах масиву не трапляється. Водночас, обидва підвиди доволі часто трапляються на Прикарпатті та Волино-Подільській височині разом з їхнім гібридом *A. moldavicum* nothosubsp. *confusum*.

Інші два гібриди, *A. moldavicum* nothosubsp. *porcii* та nothosubsp. *simonkaianum* підтверджено в Українських Карпатах виключно для регіону Мармароських гір. Ймовірно, *A. moldavicum* nothosubsp. *porcii* може бути також віднайдений на Чорногорі. Водночас, присутність *A. moldavicum* nothosubsp. *simonkaianum* на Волино-Поділлі є сумнівною, оскільки немає жодного іншого підтвердження окрім єдиного зразка, що зберігається у гербарії GJO. Більше того, інші зразки зібрані Б. Блоцьким з того самого регіону виявилися такими, що належать більш тривіальному підвиду *A. moldavicum* nothosubsp. *hosteanum*.

Ми використали різні алгоритми SDM аналізу (MaXent, BioClim, GARP, EnvDist, TIN та IDW) з метою виявити алгоритм, що найбільш точно відповідає реальному поширенню *A. moldavicum* на даній території. BioClim доволі точно вказав на центри поширення виду в Карпатах, на Волино-Подільській височині, а також Польській рівнині. В той час, як традиційно прийнятий алгоритм MaxEnt недооцінив ймовірність поширення виду на територіях з підтвердженою присутністю і навпаки переоцінив – на територіях, для яких вид невідомий. IDW алгоритм продемонстрував подібні до MaXent результати і підтвердив можливість використання з метою моделювання поширення видів.

Ключові слова: *Aconitum moldavicum*, Ranunculaceae, Карпати, моделювання поширення видів