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A SPATIAL AND QUANTITATIVE ANALYSIS OF THE NATURAL CONDITIONS OF BLACK PINE HABITAT IN BANAT (ROMANIA)

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Abstract: Both the European continent and Romania are occupied by significate forested areas, often represented by rare species or even virgin forests. The natural distribution of the black pine (*Pinus nigra ssp. Banatica*) in the Banat region of Romania is still a pending spatial problem. Therefore, the main aim of this study is to assess the sustainability of morphometric parameters in modelling of Banat black pine in Domogled and Cernei Mountains, using Geographic Information Systems instruments. A set of morphometric parameters (altitude, depth, density, slope, and curvature), econometric climatic indicators (Martonne and FAI) and Vegetation indexes (NDVI and SAVI) have been derived from a 10m DEM, Sentinel 2 satellite images and WorldClim gridded data. For the modeled data, a contour of the area where the Banat black pine is found, which was validated by in situ mapping, was used. For the purpose of this study the dependent data set was split up into presence – absence of the Banat black pine and also the data was split into training and validation for both categories. For spatial analysis of the data ArcGIS 10.8.1 was used and for the statistical analysis R software was used. We obtained four models that used between two and six independent variables. All models were validated using AUC and R^2 McFadden and obtained very good scores (between 0,886 and 0,904 and between 0,37 and 0,42 respectively). The most important predictors were found to be Martonne Aridity Index, slope, and SAVI. Based on our finding we can conclude that a geomorphometric modeling approach can be used, successfully, in explaining the spatial distribution of a tree species in a marginal environment.

Key words: black pine, forest ecosystem, morphometric parameters, species distribution, statistical analysis, Banat region, Carpathians, Romania.

1. INTRODUCTION

Management and conservation of the forest biodiversity is an important global issue that concerns the ecologically use of forest (Lindenmayer et al., 2008; Thom & Seidl, 2016). Some shortcomings identified, be research, in the last two decades were about spatial, time and management of the landscape (Lindenmayer et al., 2008). At continental level Europe has almost 100.000 protected areas, which is more than any other continent. Mountain forests represent one of the most important world ecosystems, and, also, according to European Environment Agency (EEA) forest is the most predominant ecosystem in Europe. In Europe these natural areas are part of a Europe wide network called Natura 2000 (Maes et al., 2012), and almost 46% of primary forest are under strict protection (IUCN Category I) (Kulakowski et al., 2018**)**. EEA has also revealed that Europe was covered, in the past, by approximately 80% with forest. Bennett et al., (1991) considers the late Neogene-Quaternary climate changes as a key cause of the recent European tree flora (*Pinaceae*, *Beech family)*, both warm and cold stages being responsible for the presence or extinction of some species in Northern Europe, and in Southern Europe (Svenning et al., 2008). The environmental conditions were the cause for the survival tree species in the southern part of the continent as well (Bennett, et al., 1991; Bottema et al., 1995; Svenning et al., 2008). The Last Glacial Cycle is supposed to have made changes in the flora distribution of Central and Eastern Europe (Feurdean et al., 2014), as in the case of the black pine species, which is specific to the Mediterranean region (Di Pasquale et al., 2020).

According to Sabatini et al. (2018) Romania is one of the countries from Eastern Europe where primary forest ecosystem is mostly located in the mountain region. Romanian Carpathians occupies almost 21% of the country (Niculae et al., 2017). Due to the Romanian environmental laws, the diversity of the flora is a leading indicator in the assessment and the management of a forest ecosystem (Doniţă et al., 2005). In the Banat region of Romania, the Mediterranean climatic influence becomes responsible for the presence here some endemic species: *Linum uninerve, Primula auricula ssp. serratifolia, Athamanta turbith ssp. Hungarica and Pinus nigra ssp. Banatica* (Dumitriu-Tătăranu & Florescu, 1965).

Most studies consider black pine a wide-spread (Kaya et al., 1985; Kulakowski et al., 2018; Mikulová et al., 2019), having its origins in the geological past of the Mediterranean areas of Europe - Mediterranean Islands, Balkan Peninsula, Iberian Peninsula, South of France, South of Italy (Levanič et al., 2012). Separation of black pine at European level occured due to natural environmental conditions, such as physical and chemical particularities of the substrate, expressed by ecological requirements (Isajev et al., 2004). In Romania, the Banat black pine is found in three specific areas in the Southwest of the country: Domogled – Cerna Valley National Park, Almăjului Mountains, and Vâlcanului Mountains (Pătroescu et al., 2007), in Domogled Massif being the largest population (Levanič et al., 2012). The Banat black pine represents an emblematic species for the Domogled – Cerna Valley National Park, and due to its historical evolution and ecological particularities, the Banat black pine represents one of the most important key species for ecological modeling.

Pătroescu et al., (2007) have revealed in their study that the main natural conditions of the black pine habitat are steep limestone slopes, fragmented landforms, aridity, and Levanic et al., (2012) have shown in their study the resistivity of black pine to aridity and drought. Therefore, we considered these indicators as main factors for this species habitat. These are some of the most important ecological factors for understanding the forest ecosystem as whole system (Schupp, 1995; Dullinger et al., 2005). Many studies have shown the relationship between the forest ecosystem and the European black pine (Nikolic & Tucik, 1983; Tíscar & Linares, 2011; Enescu et al., 2016).

The morphometric parameters are important in the occurrence of climatic events such as wildfire in the coniferous forest (Sáenz-Ceja & Pérez-Salicrup, 2019), considering the steep slopes and limestone cliffs. Most studies have revealed the importance of the black pine growth dependency on climatic conditions (Piermattei et al., 2013; Proutsos & Tigkas, 2020). Thus, we used two ecometric climatic indicator, such as Forest Aridity Indicator and Martonne Aridity Index. Martonne Aridity Index is used as a climatic indicator for areas of different soil types, and to show the difference between zonal forest formations, where values increase while the altitude also increase (Chiriță, 1977). FAI expresses a higher values in a warmer and drier year with effects in the trees growth decline (Führer et al., 2011; Móricz et al., 2018). In order to analyze the density and the health level of forest we used the Normalized Difference Vegetation Index (NDVI), considered by Zhou & Troy (2008) the best in differencing of non-vegetation and vegetation. The Soil Adjusted Vegetation Index (SAVI) is used in case of a lowered vegetation index signal, especially in areas characterized by a single soil (Huete, 1988), in our case study being brown soils (*rendzinas*) (Isajev et al., 2004), and suitable for the temperate climatic conditions from Romania (Mihai et al., 2019). Considering that the southwestern part of Romania is more and more affected by drought, we hypothesized that the Banat black pine prefers arid areas, even that this causes forest disturbances.

Therefore, we propose as methodology the use of generalized linear model (GLM), which is an extension of logistic regression that works best with binary dataset (Zare Chahouki & Zare Chahouki, 2010; Salas-Eljatib et al., 2017), as in this case the presence and absence of black pine. Understanding species ecology is a process of linking accurate spatial data observations with an interrelation of these data (Azaele et al., 2015). Recent species natural distribution assessment methods pay close attention in establishing the environmental components ranking through statistical approach, such as multiple regression, the group of generalized logistic models (GLMs) (Guisan & Zimmermann, 2000; Araújo et al., 2011). After the factors significance hierarchy is settled, they are used in spatial statistical algorithms in order to define environmental conditions as a whole system (Lebourgeois et al., 2013). The result of the spatial statistical complex correlations is the most accurate indicator of environmental influences on species ecology (Prasad et al., 2006). Applying logistic regression models in ecology implies a probability of the binary response variable directly modelled, if there is considered the random nature of the analyzed event (Salas-Eljatib et al., 2017). Hence, the modeling aims to create a hierarchy of the natural condition's favorability for the Banat black pine site, and to model the distribution of the black pine in our test area.

2. STUDY AREA

The study area is part of the world-wide network Natura 2000 *Pinus nigra ssp. Banatica* site, an integrated part of the Domogled – Cerna Valley, which covers an area of 62.221 ha (Figure 1). By analytical methods it was established that the forested area of this national park is about 3046.40 ha, of which the Banat black pine forests represent approximately 1953,1 ha, and the non-forested is of forested of almost 217.41 ha (Levanič et al., 2012) 1953.1 ha (Pătroescu et al., 2007). The Cerna and Mehedinți Mountains are in the southwestern part of the Southern Carpathians. The two mountain groups are separated by the Cerna River from north to south. Being specific to a Mediterranean climate influence and a fragmented relief (Levanič et al., 2012), the Mehedinți and Cerna Mountains have a favorable environment for this species. The presence of black pine endemic species was the main reason to create this protected site in 2005 (Pătroescu et al., 2007).

The entire landscape is dominated by an expressive structural, tectonic, and lithological landform, connected with Mesozoic limestones and a complex Cerna fault system (Török–Oance, 2003-2004). Impressive cliffs, structural steps, gorges and karst landforms are defining elements of the geomorphological lansdcape (Fig. 2).

The study site is a large black pine discontinuous forest within a calcareous and karst area. Banat black pine habitat prefers xerophilous vegetation ecosystems, which are adapted to drought, and hard-to-reach limestone cliffs (Isajev et al., 2004). Thus, skeletal soils and the steep slopes are common elements in all areas where it current vegetates (Pătroescu et al., 2007). The distribution of this species is still disputed, the Banat region being exclusively part of Romania where this tree grows naturally. Recent research has revealed that lately climate changes has intensified the forest disturbance regimes, as well as the wildfires are more frequent, and the areas occupied by black pine are most affected by drought (Levanič et al., 2012; Kulakowski et al., 2018; Thom & Seidl, 2016).

3. MATERIALS AND METHODS

3.1. Data collection

In this study we used the following data:

- he Banat black pine site – shapefile data provided by the Romanian Ministry of Environment;

- A 10 meters resolution Digital Elevation Model derived from a 1:25000 military topographic map;

Ecometric climatic indicators derived from 1 km² resolution WorldClim gridded time-series of climate variables (temporal range 1970-2000):

- FAI (Forest Aridity Index) and De Martonne Aridity Index;

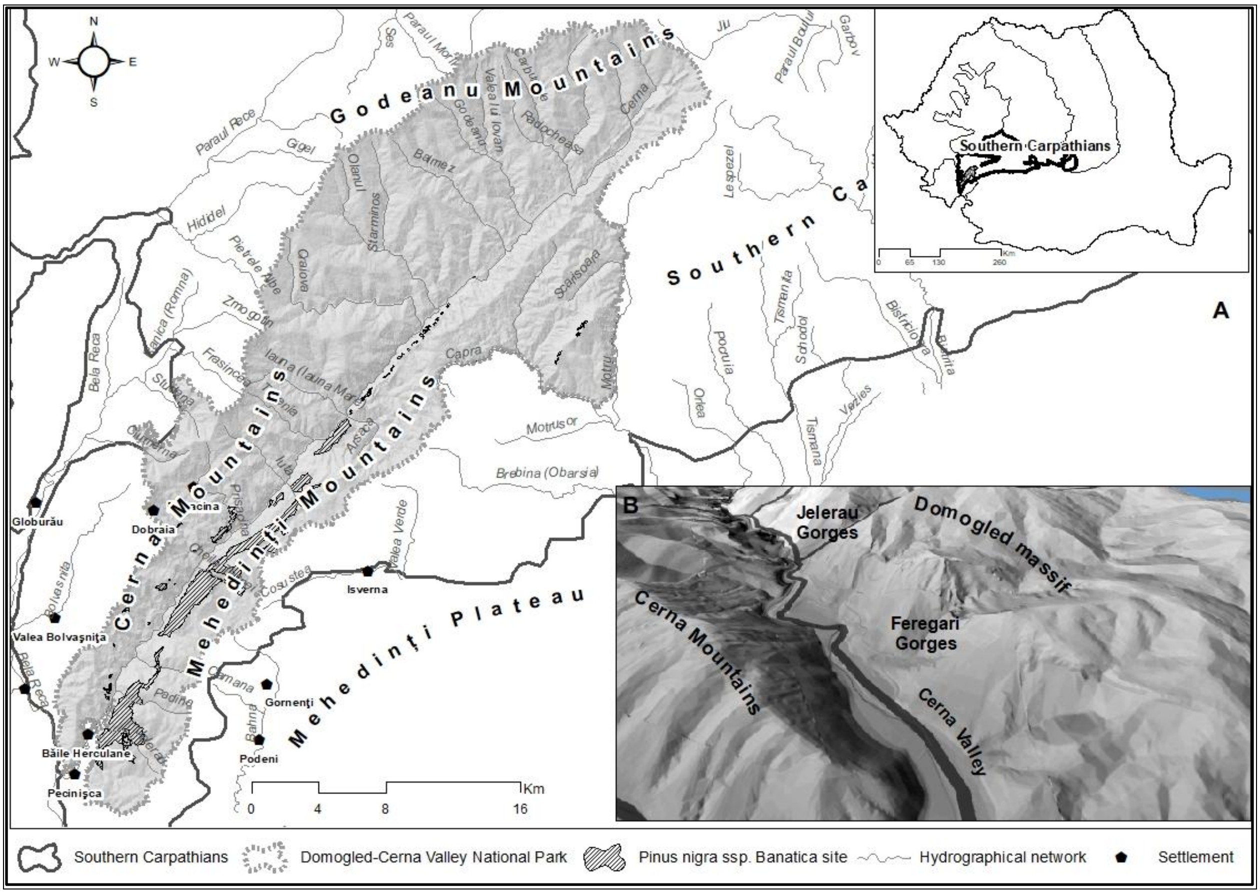

Figure 1. A - The study area location; B – DEM of the south part of Domogled-Cerna Valley National Park

Figure 2. Structural and lithological landforms in *Feregari Gorges.*

- Vegetation indices derived from a 10 m resolution Sentinel 2 satellite image recorded on April 22, 2018, such as Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI).

3.2. Binary data

Since DEM spatial resolution is close related to the ecological model accuracy, we decided that a 10 meters resolution DEM from topographic map is our study optimal (Lebourgeois et al. 2013). Thus, the first step was to convert the distribution area of the Banat black pine site (as a vector polygon) into raster data. Then each pixel was converted into a vector-point feature. The result consisted of 197238 points representing the black pine area. The largest point cluster appears in the Domogled Mountain Reservation, having the highest point in Domogledul Mare (1105 m a.s.l.), containing 81,71 % of the total (Fig.3). There were also identified smaller areas due to less favorable conditions for the development of these forests (Pătroescu et al., 2007). In the Cerna Mountains and in the northern part of Mehedinți Mountains the presence of black pine is limited due to landforms morphometry, with less fragmented relief, which is different than the one observed in Domogled Massif (Levanič et al., 2012). The location points of a species in a certain area provides valuable information for understanding the ecology of that species (Elmendorf, et al., 2012; Lebourgeois et al. 2013; Dalponte et al., 2014).

Nevertheless, recent studies have revealed that knowing the factors which impact the presence of a of a species would be pictured also by constrainers, even of negative factors or of bad ranges (Lu et al., 2020). To complete the database, we generated a new spatial database of 89756 black pine absence points in the immediate neighborhood/proximity of the presence area. Thus, the final database contains 64,4% of presence and 35,6% of absence points observations.

3.3. Explanatory Variables

The database of all points (P – presence, A-absence) was completed by five morphometric parameters attributes extracted from DEM (altitude, slope, curvature, density, depth), using tools from ArcToolbox. These are some of the most important ecological factors for understanding the forest ecosystem as whole system (Schupp, 1995; Dullinger et al., 2005).

Therefore, altitude was measure by extracting values for each point of the database using the tool *Extract values to point/Spatial Analyst*. Slope, in units of degrees, was extracted from DEM using the tool *Slope/Spatial Analyst*. The *Curvature/Spatial Analyst* tool was, used as well, to derivate each cell considering the neighboring cells, and to estimate where the local landscape is convex (positive values) or concave (negative values). Density was measure by reporting the length of the hydrographical network per unit area (generally square kilometers), using *Block statistics/Spatial Analyst*, and then the tool *Intersect/Spatial Analyst* to intersect each square to the hydrology. Depth of relief, also known as energy of relief, in units of meters, involved finding and subtracting the minimum altitude from the maximum on a certain surface using *Block statistics/Spatial Analyst*.

Ecometric climatic indicators are important biogeographical factors for the Banat black pine habitat (Pătroescu et al., 2007). Thus, we used two climatic indices: *De Martonne Aridity Index* and *Forestry Aridity Index*. De Martonne aridity index, or the ratio between the mean annual values of precipitation (P) and temperature (T) plus 10°C. Forestry Aridity Index (FAI) (or $T_{VII-VIII}$ /(P_{V-VI}) +$(P_{VII-VIII})$). Therefore, for each point of presence was extracted multiannual average, minimum, maximum temperatures and the same for precipitations from the 1 km² gridded WorldClim database (Fick & Hijmans, 2017). A recent study conducted by Sangüesa-Barreda et al., (2019) has revealed that drought impacts the growth of black pine in Mediterranean basin by increasing the desynchronization. At first, we thought the data

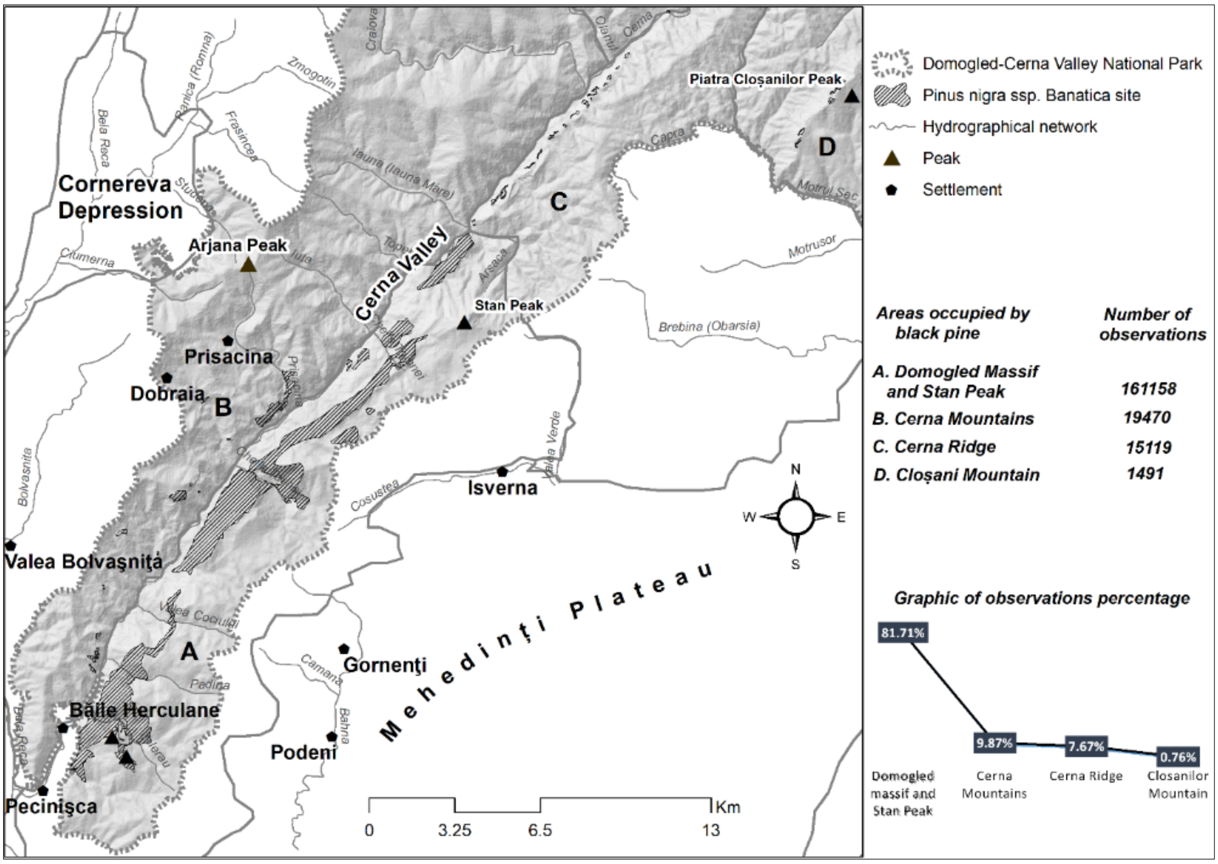

Figure 3. Distribution area of the Banat black pine.

resolution difference would give uncertainty results (Heuvelink & Stein, 1989; Devendran & Lakshmanan, 2014), but there are many ecological studies that used this dataset (Stone & Laffan, 2013; Winder, 2014; Wango et al., 2018) and have proved in their study that most of the data from WorldClim dataset, with the exception of precipitation data, give similar data as the ones taken from meteorological stations.

Finally, remote sensing data contain important spatial information (Blaschke et al., 2000; Alsharrah, et. al., 2016; Gibson et al., 2018). And the Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index were extracted from the Sentinel 2 satellite image.

3.4. Methodology

The use of statistical analysis consisted in finding best models of the logistic regression, to make prediction of presence and absence (Guisan & Zimmermann, 2000) of the Banat black pine, on basis of the natural conditions to be defining for the habitat of this species (Isajev et al., 2004).

The data processing (e.g. preparation of the binary dependent variable and independent variables) was performed using ArcMap 10.8.1 software. The statistical analysis was performed using R free software environment (R core team. 2018). The whole methodology implies both processing the data, and the statistical analysis as shown in the Figure 4.

The first step was to apply a very used multicollinearity occurrence diagnosis among the explanatory variables, the Pearson's correlation (Senaviratna & Cooray, 2019; Milanović et al., 2021). The method shows a multicollinearity concern in case of values greater than 0.7 (Chao et al., 2008). By applying the multicollinearity method, we could choose the independent variables suitable to model a more precise distribution of Banat black pine. At this point the database consists of eight explanatory variables - each one with a specific range for both the presence and absence of the Banat black pine. These ranges sometimes overlap, which strengthens our belief that by tacking all variables together, as a system, it would be easier to understand the ecology of a species, also highlighted in other studies (Senaviratna & Cooray, 2019; Milanović et al., 2021). Further, the whole database was randomly divided into two sets, a percentage of 70% for training, and the remains percentage of 30% to test our GLM models (Raschka, 2018).

The next step was to apply the generalized linear model (GLM) on the training dataset, by adding one explanatory variable after each computation.

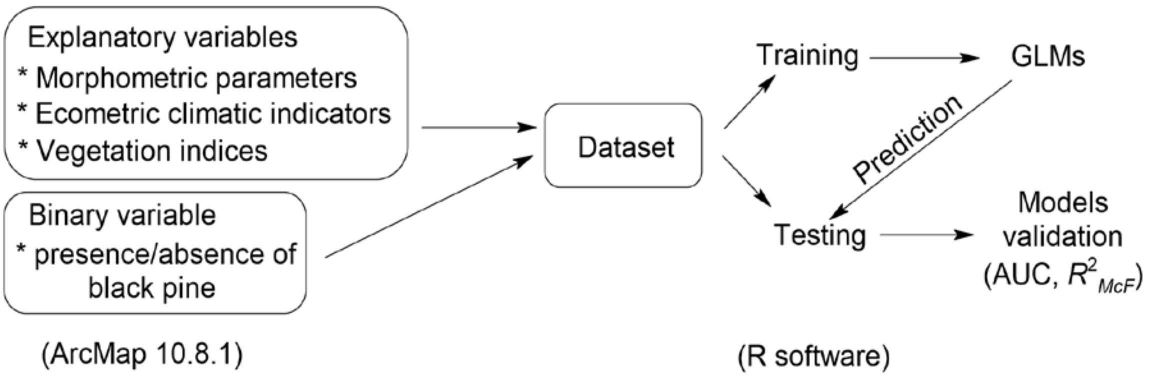

Figure 4. Workflow of data processing using ArcMap 10.8.1, and the statistical analysis using R free software environment.

Hence, there were four models based on which we could set up the hierarchy of all independent variables for the distribution of the Banat black pine.

The final step was to verify our four models by ranking them according to their area under the curve (ROC) values and R squared.

3.5. Models' validation

The models' validations are the Area under the curve (AUC), and R squared (McFadden's). AUC is considered an important evaluation metrics for models' validation, due to its practical way to outline the overall accuracy of the test (Hanley and McNeil, 1982). An AUC is the measure or degree of separability, while the Receiver Operating Characteristics curve (ROC) represents a probability curve. A greater AUC value means the model is predicting better the 0 as absence classes, and the 1 as presence classes (Giancristofaro & Salmaso, 2007).

Regarding the second model's validation, in the last decade, some studies have shown that McFadden's measure is best to calculate the R squared (Hu & Palta, 2006; Smith & Mckenna, 2013), which is defined as:

(1) $R^2_{McF} = 1 - \ln(L_M) / \ln(L_0)$;

where: ln (L_M) - the maximized likelihood for the model without any predictor; and ln (L_O) - the maximized likelihood for the model with all predictors.

4. RESULTS

4.1. The GLM results

The Banat black pine distribution in our area of interest is explained by several independent variables, which have shown significant values. Correlated variables occur due to same source of data, like in case of the Martonne and FAI, SAVI and NDVI, as shown in table 1. After adding each new explanatory variable in the logistic regression, the conditions that influence the natural distribution of the Banat black pine are more visible.

Therefore, the six variables, shown in the table 2, fit best in the GLMs, with an AIC value decreasing after adding each variable. However, the six variables, shown in the table 2, fit best in the GLMs, with an AIC value decreasing after adding each variable, and a Pearson values smaller than 0.7. The Martonne Index was considered the main independent variable. Slope and curvature are important in the study of the black pine, also revealed by others (Levanič et al., 2012), steep and sunshiny slopes represent main items in the distribution of this species, because of its growth on both extremely humid and dry habitat, and on limestone cliffs (Isajev et al., 2004). Density and depth landforms fragmentation also show significant values regarding the AIC, as the horizontal fragmentation influences the drainage system alongside the slope and expositions (Pătroescu et al., 2007). Altitude and vegetation indices, NDVI and SAVI are not so important variables, but when they are coming together with the other explanatory variables, the model is statistically improved by a lower AIC value (Table 2).

4.2. The models' validation results

The AUC performance for each one GLM shows significant values greater than 88% (Table 3), which supports the validity of each model. The differences between the models we applied are insignificant, but they have helped to model the distribution of this species more accurately. The GLM models results gave an accurate response of the spatial distribution of the Banat black pine in the area of interest. Thus, applying this additional validation we were able to show a image of favorability for presence and absence of this species in the Domogled – Cerna Valley National Park (Figure 5). The models that have predicted values more than 0.5 were considered as predicted presence, while the smaller values were considered predicted absence (Ireland, Drohan, 2015; Baeten et al., 2019). The favorability of the presence

Table 1. Correlations among explanatory variables.

	Altitude	*Depth*	*Density*	*Slope*	*Curvature*	*NDVI*	*SAVI*	*Martonne*	*FAI*
Altitude	1								
Depth	-0.513	1							
Density	-0.574	0.409	1						
Slope	-0.204	0.373	0.149	1					
Curvature	0.369	-0.249	-0.249	-0.119	1				
NDVI	0.358	-0.385	-0.269	-0.431	0.152	1			
SAVI	0.359	-0.385	-0.269	-0.434	0.156	0.976	1		
Martonne	0.820	-0.504	-0.504	-0.229	0.302	0.373	0.374	1	
FAI	-0.718	0.386	0.502	0.167	-0.248	-0.283	-0.284	-0.840	1

Table 2. The GLM models applied, with the five explanatory variables and the AIC values for each one.

The GLMs	*Explanatory variables*	*AIC*
M1	Martonne, Slope	116110
M2	Martonne, Slope, Density	109758
M3	Martonne, Slope, Density, Depth	107612
M4	Martonne, Slope, Density, Depth, Altitude, SAVI	106431

Table 3. Model validation, with the AUC values for both train and test sets, and the McFaddens R squared's values.

GLMs	*AUC train set*	*AUC test set*	*R^2McFadden*
M1	0.888	0.886	0.37
M2	0.896	0.895	0.41
M3	0.902	0.901	0.42
M4	0.905	0.904	0.42

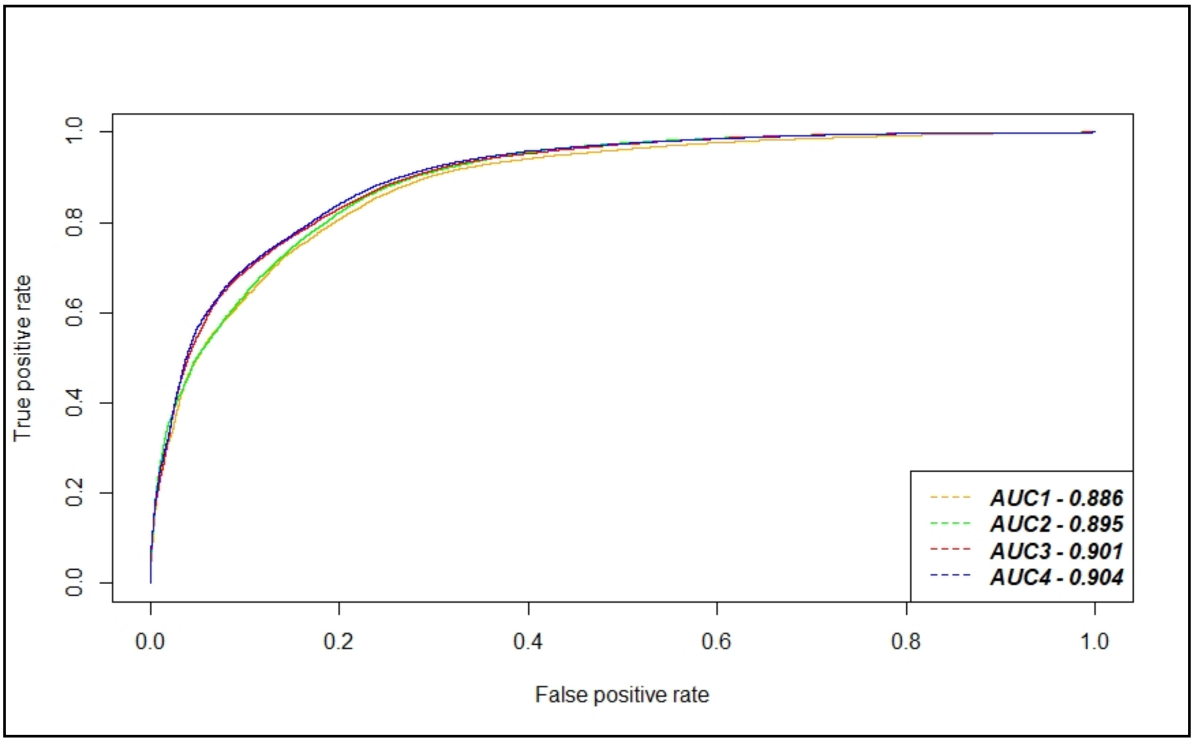

Figure 5. Plots of AUC for each GLM model (AUC1 - M1; AUC2 - M2; AUC3 - M3, AUC4 - M4).

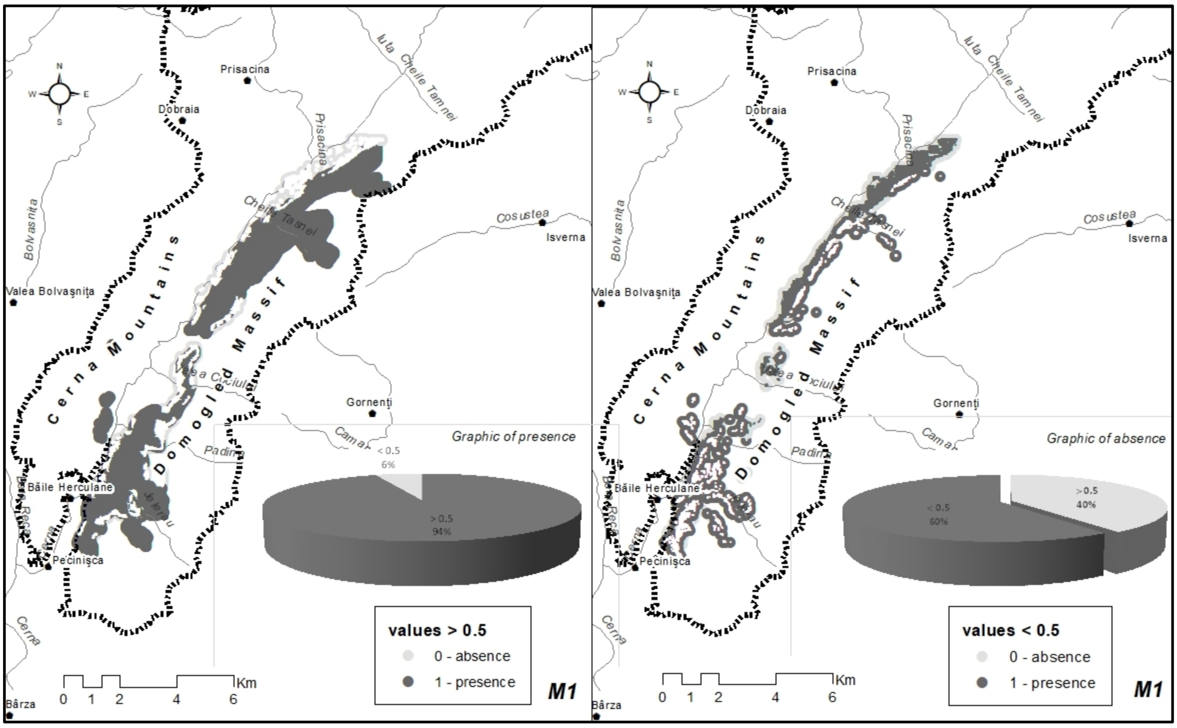

Figure 6. Distribution of data validation on the subset of testing, for both presence and absence of the Banat black pine for first GLM model (M1).

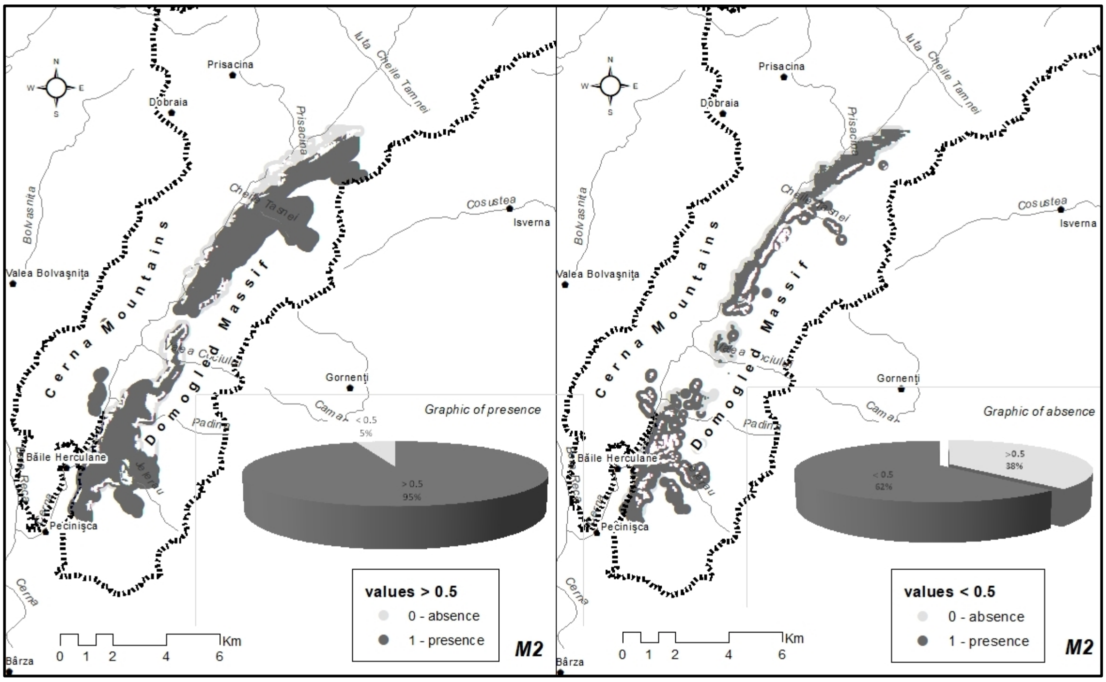

Figure 7. Distribution of data validation on the subset of testing, for both presence and absence of the Banat black pine for second GLM model (M2).

has a percentage over 90%, and the percentage of not favorability is 5% for each model. The absence is expressed as a percentage of almost 40% of favorability, and a percentage of approx. 60% of not favorability, as shown in the figures 6 – 7 – 8 - 9.

In this study we have established the hierarchy of the natural condition's favorability by using the generalized linear model to show the natural distribution of the Banat black pine. Thus, this study proves the hypothesis that the morphometric parameters, as well the drought play important roles in the Banat black pine habitat and natural distribution, as in case of the Mediterranean black pine subspecies. Further research must include field work in order to acquire more data about the Banat black pine habitat.

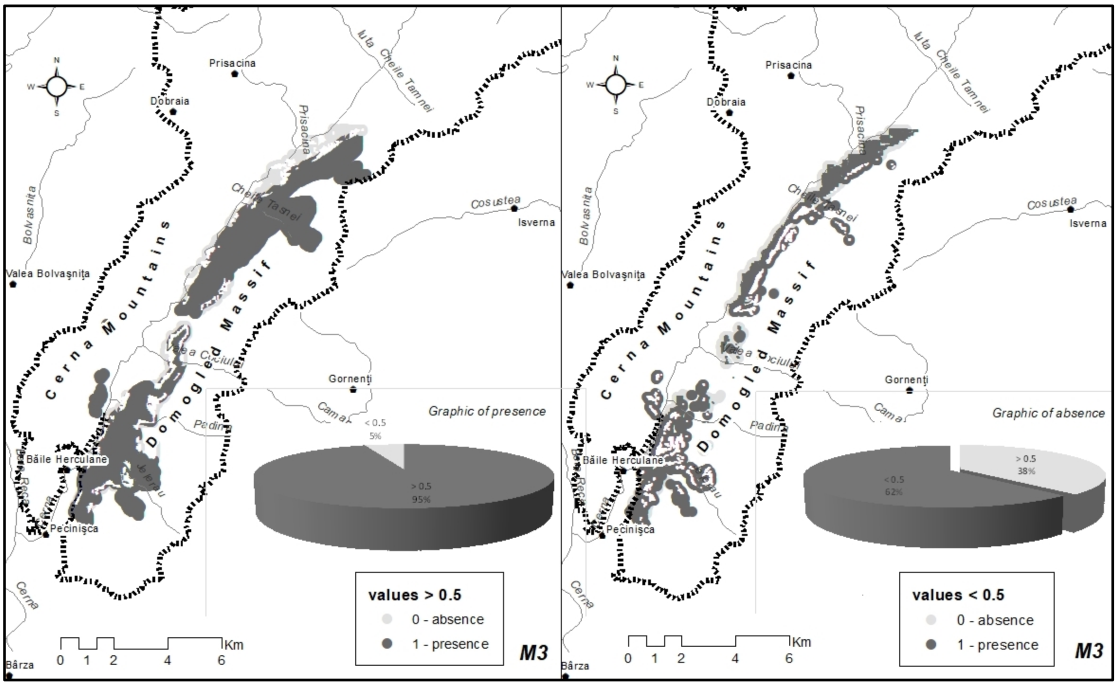

Figure 8. Distribution of data validation on the subset of testing, for both presence and absence of the Banat black pine for third GLM model (M3).

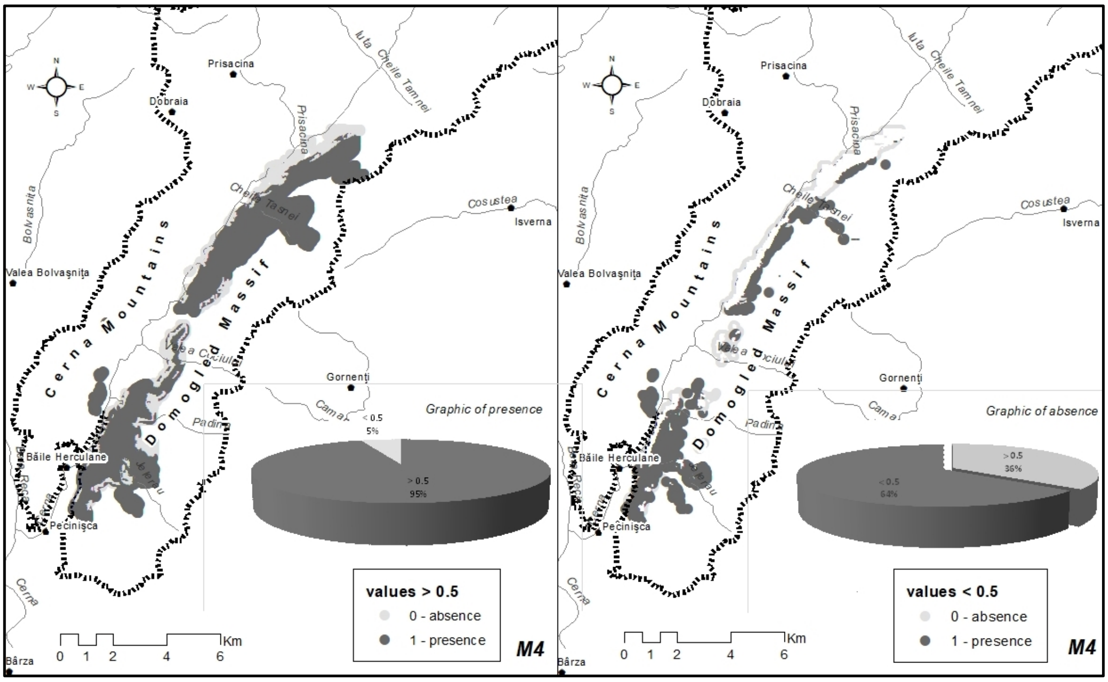

Figure 9. Distribution of data validation on the subset of testing, for both presence and absence of the Banat black pine for forth GLM model (M4).

5. DISCUSSION AND CONCLUSIONS

The study shows the correlation between the black pine habitat characteristics and its natural distribution, and it represents an important first step in the statistical analysis of the Domogled Massif sustainability for the Banat black pine tree. The accuracy of validation model confirms that the GLM is the best statistical distribution model of the Banat black pine, for now. The high accuracy assessment of our regression models led us to graphical response of the distribution of the Banat black pine, with higher values of AUC (i.e., 0.9) in all four models (Shtatland et al., 2014).

As stated in a study about the *Anatolia* black pine distribution in Turkey, the morphometric parameters are important factors which influence the distribution of black pine (Atalay & Efe, 2012).

Therefore, the results obtained in this study support the claim of similarity between the two species (Boşcaiu & Boşcaiu, 1999). They determined a specific microclimate which has an important role in the presence of the Banat black pine on the limestone cliffs and valley sides, in all mountain ranges. Comparing to the other black pine sites from the European continent which are climate related (Isajev et al., 2004), the Banat black pine, as well the Arnold black pine habitats are strongly influenced by landforms morphometry. In the case of both species, the drought became lately a serious problem, which affect their growth and distribution (Móricz et al., 2018).

In the last decades, the habitat of the Banat black pine is confronting drought, and the distribution of this species is still an unsolved scientific problem. Only few studies on it have revealed the forests general condition, and habitat associations based on field research (Pătroescu et al., 2007; Levanič et al., 2012). According to this information the statistical spatial analysis used in this study highlights the distribution of the Banat black pine, considering the morphometric parameters, ecometric climatic indices and vegetation indices.

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