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THE POTENTIAL IMPACT OF CLIMATE CHANGE ON THE DISTRIBUTION OF NORWAY SPRUCE (*Picea abies* Karst.) IN BOSNIA AND HERZEGOVINA

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Abstract. As forests in Bosnia and Herzegovina cover 2,904,600 ha or 56.7 % of its total area, and since the meteorological data analysis for the period 1961–2014 shows that the mean annual temperature maintains a continuous rise, close attention should be paid to these fragile ecosystems. It is important to note that one of the most economically valuable species for forestry in Bosnia and Herzegovina, Norway spruce, is particularly endangered due to its very low drought resistance and spread of various diseases. Comparing the last climate sequence (1991–2019) with the previous one (1961–1990) we found that the spruce-inhabited areas showed an average increase in the values of the Forest Aridity Index of 0.929. As for the Ellenberg's climate quotient, it is noticeable that climate change is not as strong as in the case of the Forest Aridity Index. Based on projections for the mid- (2041–2070) and late-century (2071–2100) under the RCP 4.5, there will be no change that is likely to significantly affect the distribution of spruce. The predicted rates of decline and altitudinal shifts of favorable habitats are negligible. On the contrary, projections under the RCP 8.5 predict a significant reduction of suitable habitats, both for the existing range of Norway spruce and the entire territory of Bosnia and Herzegovina. Particularly, late-century projection under the RCP 8.5 predicts an almost complete reduction of suitable habitats, while small areas of suitable habitats at higher elevations will remain intact.
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ПОТЕНЦИАЛЬНОЕ ВЛИЯНИЕ ИЗМЕНЕНИЯ КЛИМАТА НА РАСПРОСТРАНЕНИЕ ЕЛИ ОБЫКНОВЕННОЙ (*Picea abies* Karst.) В БОСНИИ И ГЕРЦЕГОВИНЕ

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Аннотация. Леса в Боснии и Герцеговине занимают 2 904 600 га, или 56,7 % от общей площади страны. Анализ метеорологических данных за 1961–2014 гг. показывает, что среднегодовая температура воздуха продолжает постоянно повышаться, поэтому лесным экосистемам следует уделять пристальное внимание. Одним из важнейших видов для лесного хозяйства Боснии и Герцеговины является ель обыкновенная. Этот вид находится под угрозой исчезновения из-за его очень низкой засухоустойчивости и подверженности различным заболеваниям. Сравнивая последний климатический период (1991–2019 гг.) с предыдущим (1961–1990 гг.), мы обнаружили, что в покрытых елями районах наблюдалось увеличение значений индекса засушливости леса (FAI) в среднем на 0,929. Климатический коэффициент Элленберга (EQ) существенно не изменился. Согласно прогнозам на середину (2041–2070 гг.) и конец века (2071–2100 гг.) в соответствии со сценарием RCP 4.5 значительного влияния климата на распространение ели не будет. Прогнозируемые темпы уменьшения площади и высотные сдвиги благоприятных местообитаний незначительны. Прогнозы в соответствии со сценарием RCP 8.5 предсказывают весомое сокращение благоприятных местообитаний для ели обыкновенной как на территории существующего ареала вида, так во всей Боснии и Герцеговине. В частности, прогноз на конец века (RCP 8.5) показывает почти полное исчезновение благоприятных для произрастания ели мест, в то время как небольшие участки, подходящие для этого дерева, расположенные выше, чем остальные, над уровнем моря, останутся нетронутыми.

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Ключевые слова: ель обыкновенная, ROC-анализ, изменение климата, распространение ели, сценарии RCP.

Introduction

According to the Second State Forest Inventory in Bosnia and Herzegovina, forests cover 2,904,600 ha or 56.7 % of its total area [1]. One of the three most economically important species for forestry in Bosnia and Herzegovina is Norway spruce [7, 17], which is particularly endangered as a result of its very low drought resistance [28] and the spread of various diseases [4]. Spruce rarely occurs alone as an edificator, most often in communities with fir or beech and fir [7]. According to the Second State Forest Inventory in Bosnia and Herzegovina, these forests cover 702,200 ha [1] or 24.18 % of the total forested area. Generally, after the retreat of glaciers (10–12 thousand years ago), first of all birch started to expand its area to the north, and then pine and spruce appeared 7,000 years ago. Over the next 5–6 thousand years, the area of spruce expanded significantly all over the continent [32].

Currently, due to unfavorable influences of abiotic and biotic factors, there is a decreasing trend in the area under spruce, and the species is considered biologically weaker compared to other species from the communities they build together [7, 23]. It's interesting that in mixed spruce-fir stands on well-drained and rich soils, fir mostly outgrows spruce and can temporarily suppress it under its canopy and even displace spruce from the stand [28]. One of the main reasons for forest successions is climate change. Special attention should be paid to years with extreme climatic conditions, such as years with droughts and forest fires, which are accompanied by a decrease in groundwater level. The same consequences can be observed as a result of severe frosts in snowless winters, when even spruce stands, especially its undergrowth, can die on a mass scale. The main reason for a very low drought resistance of spruce can be found in the fact that its roots are located in the upper soil horizons [28]. Kolesnikov [15] saw the main reason for the dieback of spruce forests in the impact of periodic spring-summer droughts that can cause the death of old stands. According to Melekhov [21], regardless of the type of succession, the strong exogenic factors, such as sharp increase in temperature, lead to the replacement of shade-tolerant species by light-demanding species. In the Caucasus, there is an active succession where spruce is replaced by aspen, birch and hornbeam [21].

In the past two decades the seasonal rainfall and rainfall distribution are much disrupted in Bosnia and Herzegovina, which along with rising temperatures causes problems with droughts and floods. Analysis of meteorological data for the period 1961–2014 shows that the mean annual temperature maintains a continuous rise. The increase in annual air temperature ranges from 0.4 to 1.0 °C, while the increase in temperature during the growing season (April–September) even reaches 1.0 °C. As a consequence of global warming, more frequent occurrence of extremes is expected through climate change, threatening the functioning of forest ecosystems [24]. Taking into account the above facts, it is extremely important to monitor and, to the extent that modern technology and science allow, to predict possible effects of climate change on forest ecosystems. The main purpose of this paper is to point out the potential changes in horizontal and vertical distribution of Norway spruce in Bosnia and Herzegovina.

Objects and Methods of Research

Data on the spatial distribution of Norway spruce were downloaded from the website of the Joint Research Center of the European Commission (https://data.jrc.ec.europa.eu/collection/FISE). The data according to de Rigo et. al. [10] were computed using the FISE harmonised European dataset of taxa presence/absence and available in raster form for the area of Europe (EU28 plus part of other countries within the spatial extent). In this case, the spatial distribution of forest species was estimated through statistical interpolation based on the integration and harmonization of various datasets, such as European national forest inventories and pan-European projects: BioSoil, Forest Focus/Monitoring, EUFGIS, GeneticDiversity [10].

For this analysis, the Norway spruce distribution raster was processed in the statistical environment R Studio [27] using the packages “base” [27], “rgeos” [3], “rgdal” [2] and “raster” [14] to obtain vector and raster distribution data for Bosnia and Herzegovina, especially the binary distribution raster. The process of making this raster is based on the definition of mixed stands which indicates that all stands in which the number of trees of a certain species is less than 10 % are considered pure [16], whereby such a presence of the observed species can be defined as marginal. Accordingly, the climatic characteristics of the area where the marginal presence of spruce is recorded cannot indicate the conditionality of its occurrence with specific climatic characteristics, because its presence in such areas may be due to microclimatic conditions. Thus, a binary distribution raster is obtained by reclassification, where the number 1 (one) denotes all pixels that have a value equal to or greater than 0.10 (10 %), i.e. the value that according to de Rigo et. al. [9] is characterized by a medium-low presence probability of the selected species, and the number 0 (zero) denotes all other values.

Climate data for the observed period (1990–2019) were taken from the E-OBS gridded dataset v21.0 [6], while the RCP 4.5 and RCP 8.5 climate scenarios were selected for the mid- and late-century projections [18]. To illustrate the past and present climate we used the Forest Aridity Index (FAI) suggested by Führer E. et al. [13] and Ellenberg’s climate quotient (EQ) suggested by Ellenberg H.H. [11]:

$$\mathrm{FAI} = \frac{100\,\frac{T_{\mathrm{VII}} + T_{\mathrm{VIII}}}{2}}{P_{\mathrm{V}} + P_{\mathrm{VI}} + 2P_{\mathrm{VII}} + P_{\mathrm{VIII}}};$$

$$\mathrm{EQ} = \frac{\mathrm{T_{VII}}}{P_a} \cdot 1000,$$

where, T_{VII}, T_{VIII} – average temperature in the selected periods, °C; P_{V}, P_{VI}, P_{VII}, P_{VIII} – average precipitation in the selected periods, mm; P_a – annual average precipitation, mm; V, VI, VII, and VIII – selected periods, months.

Climate data processing was also performed in the statistical environment R Studio [27] using some of the above packages, such as “base” [27] and “raster” [14], with “ncdf4” [22] package to manage netCDF file of E-OBS gridded dataset.

To examine the ability of the FAI and EQ to predict the presence of Norway spruce, the Receiver Operating Characteristic (ROC) analysis was performed using the “pROC” [26] package. The usual approach in the ROC analysis implies that the predictive probability map is compared with the actual binary event map, with various thresholds applied to the probability map to produce a sequence of binary predicted event maps and to assess the coincidence between predicted and true events [19]. The resulting ROC curve is defined as a two-dimensional graph showing the relationship between sensitivity (true positive rate) and specificity (true negative rate) [33].

One of the objectives of the ROC analysis is to examine whether it deviates statistically significantly from the reference line, the one passing through the middle of the graph [25], which is expressed using a summary metric called area under the curve (AUC) that connects the points obtained by the various thresholds [19]. One point in the ROC chart can be considered superior than the other if it is located more towards the "northwest" [12], i.e. when the proportion of true positives and true negatives is higher. Accordingly, we have used a point (threshold) that maximizes the sum of sensitivity and specificity [8, 30]. To determine whether the obtained point (threshold) has a discriminating ability to explain the distribution of Norway spruce we have used classification by Yang and Berdine [33] where values of AUC <0.5 indicate non-existent discrimination, 0.5–0.6 – poor discrimination, 0.6–0.7 – acceptable discrimination, 0.7–0.8 – excellent discrimination, and >0.9 – outstanding discrimination. To eliminate the possibility of error as little as possible, we have omitted indices with less than excellent discrimination from the prediction analysis.

To evaluate the range of the FAI and EQ within Norway spruce distribution, descriptive statistics for the Norway spruce distribution was calculated using "raster" [14] and "base" [27] packages. To show the trends of the FAI and EQ in the analyzed areas, we calculated the difference between the FAI and EQ mean values of the reference (1991–2019) and past (1961–1990) climate sequences. Determination of mean altitude within spruce distribution, as well as assessment of altitudinal shifts of climatically suitable habitats, was performed in R Studio [27], using packages "raster" [14], "rgdal" [2], "base" [27] on the basis of Digital Elevation Model which was used by Marchi et al. [18] to create RCP datasets. Final processing of raster and vector data, i.e. their visualization, was performed in GIS software ArcMap 10.5.

Results and Discussion

When we talk about the mean values of the FAI and EQ, it is extremely important to define which climatic conditions expressed through these indices are favorable for the development of Norway spruce. According to Führer et al. [13] the FAI values less than 4.75 define climatic conditions conducive to European beech growth and development. Considering that Norway spruce in Bosnia and Herzegovina often shares the habitat with European beech and Silver fir [29], we can assume that this classification of the FAI, to a certain extent, corresponds to the ecological needs of Norway spruce. These statements are consistent with the results of the research carried out by Stojanović D.B. et al. [31] in Serbia, which showed that Norway spruce corresponds to a slightly humid climate (FAI = 4.00) compared to European beech (FAI = 5.6). Therefore, our results for the previous climate series indicate that the areas where the presence of Norway spruce was recorded are still classified as climatically optimal FAI = 4.150 (table 1). However, comparing the last climate sequence (1991–2019) with the previous one (1961–1990) we found that there was an increase in the FAI values in areas where Norway spruce is present, 0.929 on average (table 1). This is very important as Führer et al. [13] state that the FAI values in the range of 4.75–6.00 are defined as climate suitable for the development of pedunculate oak and hornbeam, which suggests that the climatic conditions for Norway spruce, in terms of optimality, deteriorated during the last climate sequence (table 1). In this case, the Norway spruce suitable habitat narrows in favor of species that prefer a slightly arid climate. When it comes to extremes, there is a tendency for the maximum values to increase significantly more than the minimum values (table 1). A logical explanation for this phenomenon can be found in the fact that the maximum values are located in areas with lower altitudes that are first exposed to climate change.

Table 1

Observed climate change

Descriptive statistics	FAI			EQ		
	1961–1990	1991–2019	Δ	1961–1990	1991–2019	Δ
Minimum	3.077	3.648	0.571	12.654	13.696	1.042
Mean	4.150	5.079	0.929	16.758	18.430	1.672
Maximum	6.001	7.510	1.509	24.605	26.617	2.012
Range	2.924	3.862	0.938	11.951	12.921	0.970
Standard deviation	0.603	0.773	0.170	2.412	2.675	0.263

Analyzing the obtained values of the EQ in the reference periods (1961–1990 and 1991–2019), it is noticeable that climate change is not expressed to a large extent, as in the case of the FAI (table 1). Since the value of the EQ less than 20 indicates favorable conditions for the growth and development of European beech [11], we can conclude that the changes recorded by this index are not of great importance for Norway spruce (table 1).

Determination of the FAI and EQ predictive ability. According to the ROC analysis (fig. 1), the FAI has excellent discrimination ability to explain the distribution of Norway spruce in Bosnia and Herzegovina. The spatial accuracy of the obtained threshold of the FAI (84.52 %) (table 2) is at a satisfactory level and in accordance with the obtained discrimination ability. In the case of the EQ discrimination ability is classified as acceptable, and the EQ is therefore omitted from further analysis (fig. 1).

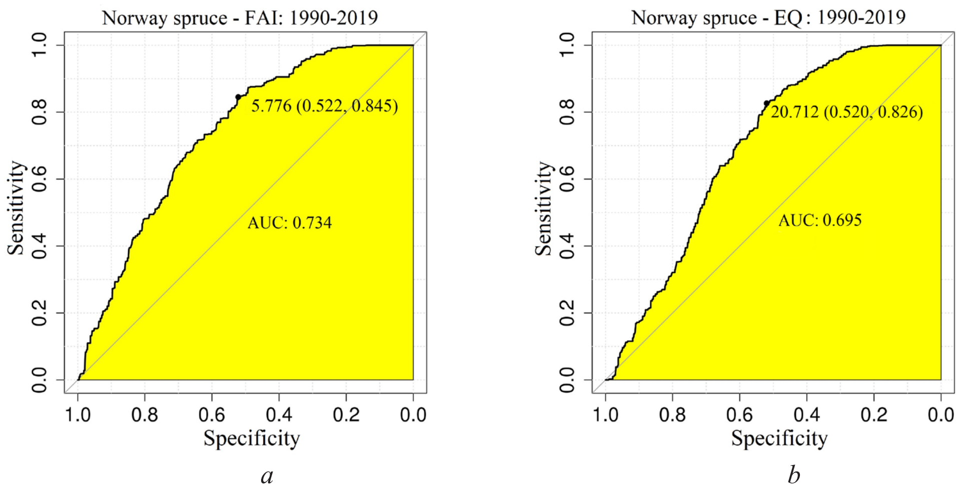

Fig. 1. The ROC graphs: *a* – FAI; *б* – EQ

To find out why the EQ gave slightly worse results compared to the FAI, see the findings of a similar survey for Montenegro carried out by Matović B. [20]. According to the author, the problem arises in the fact that areas affected by the Adriatic climate (in our case predominantly the region of Herzegovina) have large amounts of precipitation outside the vegetation period, which do not have a direct impact on the growth of forest trees, and thus systematically reduce the values of the EQ. Consequently, there is a decrease in sensitivity and specificity, which leads to a decrease in AUC and discrimination ability.

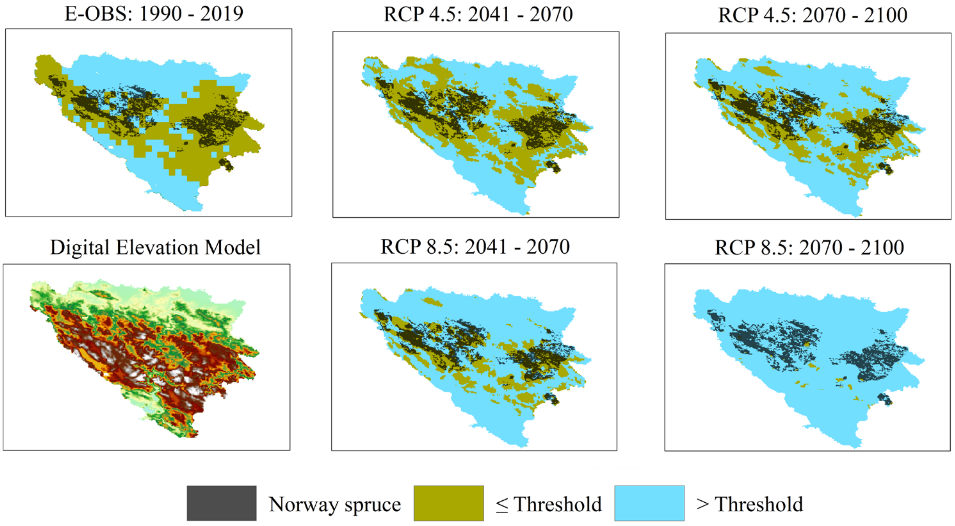

Fig. 2. Map of the current forest tree species distribution over the FAI maps for projected climate (RCP 8.5 for periods 2041–2070 and 2071–2100)

Norway spruce distribution projections based on the RCP 4.5 and RCP 8.5 climate scenarios. As shown in fig. 2, the climate scenario RCP 4.5 for the mid- (2041–2070) and late-century (2071–2100) does not predict significant changes in the FAI in areas inhabited by Norway spruce. Moreover, the mid-century projection predicts a slight increase (7.15 %), while the late-century projection predicts a slight decrease (-6.57 %) in climate-suitable habitats within the existing range of Norway spruce (table 2 and fig. 1).

According to the mentioned scenario (RCP 4.5) and its mid- and late-century projections, there will be no significant shifts (or narrowing) of climatically suitable habitats to higher altitudes (table 3). As for the entire territory of Bosnia and Herzegovina, climate scenarios predict slightly more intense shifts. The projections under the RCP 4.5 climate scenario predict a shift up to 169.31 m or narrowing of climatically suitable habitats, which is also indicated by a decrease in the standard deviation (table 3). In this case, it is noticeable that climatically unsuitable areas are spreading to the detriment of suitable ones, predominantly in areas with lower altitudes around the inner Dinaric Alps, which is not of great importance for Norway spruce due to its absence in these areas (fig. 4). This phenomenon is especially evident under the RCP 4.5 late-century projection (table 1).

Table 2

Relative difference between observed and projected climatically suitable habitats calculated on the basis of the FAI

Climatic sequence		Existing distribution	In Bosnia and Herzegovina
		%	
E-OBS	1990–2019	84.52	53.26
RCP 4.5 Δ	2041–2070	+7.15	-4.97
	2071–2100	-6.57	-35.59
RCP 8.5 Δ	2041–2070	-22.67	-49.89
	2071–2100	-99.98	-98.31

Table 3

Absolute difference between altitudes of climatically suitable habitats in the observed and future periods, calculated on the basis of the FAI

Climatic sequence		Existing distribution		In Bosnia and Herzegovina	
		m			
		MEAN	SD	MEAN	SD
E-OBS	1990–2019	1007.49	258.53	896.43	372.55
RCP 4.5 Δ	2041–2070	-8.02	-5.84	+38.48	-12.98
	2071–2100	+43.52	-35.38	+169.31	-68.25
RCP 8.5 Δ	2041–2070	+96.03	-60.16	+254.49	-101.19
	2071–2100	+548.03	-146.06	+806.94	-237.27

Contrary to the above projections, the RCP 8.5 shows extremely worrying results. The mid-century projection predicts a level of reduction that will be up to five times higher than the value predicted by the late-century projection under the RCP 4.5. Nevertheless, the late-century projection (2070–2100) under the RCP 8.5 shows the worst results. In this case, the reduction of climate-friendly habitats, within the existing range of Norway spruce, will be almost complete (table 2 and fig. 1). To a somewhat greater extent, the reductions of suitable habitats are more pronounced on the entire territory of Bosnia and Herzegovina, with the expansion of climatically unsuitable habitats having the same direction as in the case of the mid-century projection under the RCP 4.5. According to the RCP 8.5, habitats suitable for Norway spruce will be reduced to smaller areas at higher altitudes (table 3). The main reason for this lies in the fact that in such areas there is a higher average amount of precipitation. These results are in line with the results obtained by Buras A. and Menzel A. [5], which also state that according to the RCP 8.5 Norway spruce will withdraw from its habitats in Southeast Europe towards higher altitudes in the Alps and the Carpathians. Also, the mentioned authors claim that according to the RCP 4.5, there will be significantly milder changes in terms of spruce distribution, which is in line with our results.

Conclusion

The climate scenario RCP 4.5 for the mid- (2041–2070) and late-century (2071–2100) does not predict significant changes in the FAI in areas inhabited by Norway spruce, and there will be no significant shifts (or narrowing) of climatically suitable habitats to higher altitudes.

Contrary to the above projections, the RCP 8.5 shows that the mid-century projection predicts a level of reduction that will be up to five times higher than the value predicted by the late-century projection under the RCP 4.5. In this case, the reduction of climate-friendly habitats, within the existing range of Norway spruce, will be almost complete on the entire territory of Bosnia and Herzegovina.

According to the RCP 4.5 and RCP 8.5, habitats suitable for Norway spruce will be reduced to areas at higher altitudes.

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