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ASSESSMENT OF DROUGHT RELATED CLIMATE CHANGE IMPACTS ON FORESTS IN BULGARIA

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Abstract

The paper presents projections for change of air temperature and precipitation during the period 1951-2000, for 2050 and 2070 based on analysis of climate elements in the forests of Bulgaria in XX century, and application of global circulation models, WorldClim data and scenarios of IPCC Fifth Assessment Report (2014). Considerable increasing of air temperature is expected, together with decreasing of precipitation during the vegetation season. The vulnerability zones of forest ecosystems are delineated and particularly vulnerable of them will be the forests within the range from 0 to 800-900 m a. s. l., mainly in the Continental-Mediterranean climatic zone of the country. Problems are expected for more sensitive representatives of genus *Quercus*, for beech foothills ecosystems and particularly, for coniferous plantations out of their natural area of distribution. The need for implementation of already established special programs for adaptation of forest ecosystems of Bulgaria to future climate change, including the new systems of close-to-nature silviculture, increases.

Key words: global climate changes, climate projections, drought impact, forest vulnerability zones, Bulgarian forests

INTRODUCTION

Substantial information and numerous indications about accelerated accumulation of greenhouse gases in the atmosphere and continuous climate change have been gathered during the last decades (IPCC, 2007, 2014). The increase of temperature and changes in precipitation regimes form a new environment. A process of soil defreezing started in Alasca and Siberia, followed by accelerated growth of forest vegetation (Sedjo, 1991; Jacoby, 1993; Lloyd et al., 2003). Forest tree species, typical for the taiga, penetrate into the tundra (Sedelnikov et al., 1997). Upper tree line is increasing in the Alps and in the other high mountains of Europe (Walther, Grundman, 2001). The drought periods in Bulgaria and Southeastern Europe became more frequent in the second half of XX century and in the beginning of XXI (Knight et al., Eds., 2004).

These critical facts provoked extensive studies in many countries, for modelling the processes of future climate change with the aim of undertaking preventing measures for adaptation of forest vegetation to the new ecological conditions (Strain, Thomas, 1993; Sykes, Prentice, 1996; Bolliger, 2002; Broadmedow et al., 2005; Gessler et al., 2007; Koling et al., 2007).

In the period 1994-1996 Bulgarian researchers took part in an international project including 54 countries, for studying the effect of global climate change on agriculture and forests. The first scenarios using local climatic information were developed for Bulgarian territory. An evaluation of forests' potential for accumulation of CO_2 was perfomed, Holdridge life zones were delineated and some measures for adaptation of forests in Bulgaria were proposed (Raev et al., 1995; Raev et al., 1996; Raev, Grozev, 1996, 2000; Grozev et al., 1996; Raev, 1999).

Research project was developed in which the drought of 1982-1994 was interpreted as a contemporary analog for future climate changes in Bulgaria. Natural, economic and social aspects of dessication, including in the forests, were analyzed. Measures for adaptation of forest ecosystems in the zones below and above 800 m a.s.l. were proposed (Raev et al., 1998a; Raev et al., 1998b; Raev, 2001; Knight et al., Eds., 2004).

'Programme of measures for adaptation of the forest in Republic of Bulgaria and mitigation the negative effect of climate change on them' was completed in 2011 (Raev et al., 2011). Analysis was done of the state of forests, and scenarios for climate change in Bulgaria in XX century were developed, based on the emission scenarios of IPCC (2007). Maps of contemporary climate (1961-1990) were elaborated, as well as for 2020, 2050 and 2080. Sixteen models for change of climate elements were tested, with accepting optimistic and pessimistic scenarios for the future climate parameters in Bulgaria (Alexandrov, 2011). Five vulnerability zones for forest ecosystems were delineated, based on comparative analysis by using De Martonne, Budiko, Selyaninov and Holdridge methods (Raev, Alexandrov, 2011). Detailed programme was developed, consisting of measures for adaptation of forest ecosystems in Bulgaria in XXI century by vulnerability zones (Raev et al., 2011).

The project 'Climatic Changes and their Influence on Forest Ecosystems and Water Resources in Struma River Basin' provided instructions for adaptation of forests in the region to particular ecological conditions (Marinov et al., 2012). Also, a demonstration project was developed for Panagyurishte Regional Forestry Service, including prognoses of temperatures, rainfalls and expected responses by the tree species to climate change (Kostov, 2013).

IPCC Fifth Assessment Report, presenting the newest studies on annual CO_2 emissions for XXI century, was published in 2014 (IPCC AR5, 2014). There is a necessity of development of a new approach to future climate change in each country, as well as for the assessment of drought effect on the vulnerability of forest ecosystems in Bulgaria.

The **aim** of this study was to make an evaluation of drought processes effect on the main forest ecosystems in Bulgaria in the light of global climate change, considering the newest emission scenarios of IPCC AR5.

DROUGHT IMPACT ON BULGARIAN FORESTS IN TWENTIETH CENTURY

There are three climate zones in Bulgaria (Velev, 2002): Temperate Continental climate zone; Transitional climate zone; Continental Mediterranean climate zone.

Temperate continental climate zone is characterized by cold winter and warm summer, and high annual temperature amplitude. There is well-expressed spring-summer maximum and winter minimum of precipitation (Penin, 2007). The annual precipitation sum in the plain areas is between 450 and 650 mm, while in the mountains it amounts 1000-1100 mm (Koleva, Peneva, 1990).

Transitional climate zone is characterized by warm summer and milder winter, with smaller temperature amplitude. The precipitation has two maximums (May-June and November-December) and two minimums (August and February). The total precipitation sum is almost the same as in the previous climate zone, the difference being in the seasonal distribution.

Continental Mediterranean climate zone is characterized by warm summer and mild winter, small temperature amplitude and Autumn-Winter maximum of precipitation, related to Mediterranean cyclones.

The forests of Bulgaria are distributed in the three climate zones but better ecological conditions are formed at mean annual temperature from 11 to 4°C, and at altitudes from 500-600 to 1600-1800 m, in the conditions of temperate and cool mountain climate. Precipitation is 720-1000 mm in the optimum forest climate zone at 900-1700 m (Raev, 1983).

During the most severe climate drought in XX century (1982-1994) in Bulgaria, the temperature in the coniferous forests was 1.0-1.4°C higher than the normal one, and the precipitation was 12.3-15.9% lower. The temperature in the oak forest zone, i.e. from the sea level to 800-900 m in the same period was 2°C higher than the norm. Precipitation in the period 1982-1994 was on average 16% lower, and in 1990 and 1993 were lower than the normal with 24.6% and 28.7%, respectively. This caused death of 18.5% of Austrian Black pine (*Pinus nigra* Arn.) and Scots pine (*Pi-*

nus sylvestris L.) plantations in lowland forest zone, i.e. below 800 m (Raev, Rossnev, 2004). The main reason of this disaster for Bulgarian forests was the inadequate afforestations with these conifers out of their natural area of distribution (from 800-900 to 1600-1800 m), combined with the global warming started in the second half of XX century (Raev et al., 1995, 1996; Grozev et al., 1996; Raev, 2001; Knight et al., Eds., 2004). Substantial damages in the coniferous monocultures were recorded in the three climate zones, with the highest share in Continental Mediterranean climate zone, where the precipitation during the vegetation season is the lowest.

METHODS

This work is a part of the international project 'Integrated Drought Programme in Central and Eastern Europe', studying the effect of drought on agriculture, forests and water in ten countries of Central and Eastern Europe (GWP CEE, 2015). The four Representative Concentration Pathways (RCPs) of IPCC AR5 (Fig. 1) (IPCC AR5, 2014) were accepted as a general base for projection of future climate change in the forests of Bulgaria, Slovenia, Lithuania and Ukraine.

The pathways are used for climate modeling and research. They describe four possible climate futures, all considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs (RCP2.6, RCP4.5, RCP6, and RCP8.5), are named after a possible range of radiative forcing values in the year 2100 (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively). These pathways were

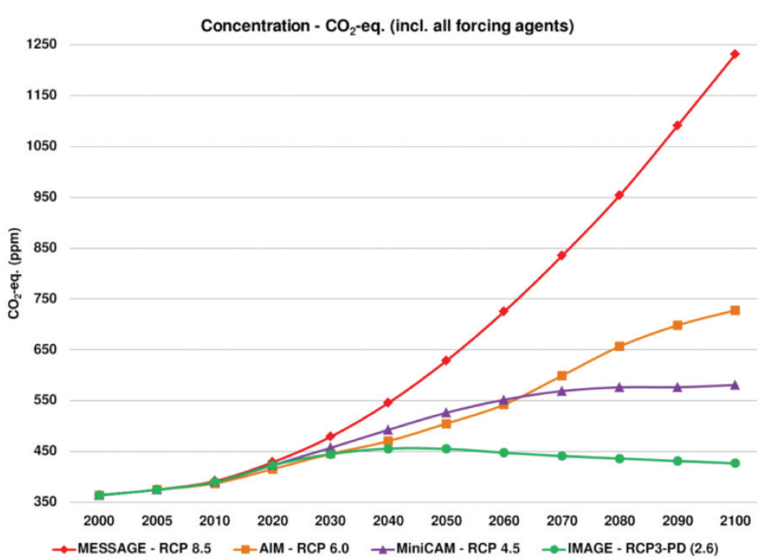

Fig. 1. Representative Concentration Pathways RCP2.6, RCP4.5, RCP6.0 and RCP8.5 (IPCC AR5, 2014)

used in this article assuming that RCP2.6 is an optimistic scenario and RCP8.5 is a pessimistic scenario.

The global climate models (GCMs) were used for the evaluation of the future concentrations of GHGs and aerosols in the atmosphere and their influence on the expected climate. Therefore, the climate models use as admission information the warming already observed, as well as the expected warming as a result of climate scenarios.

GIS software was used (ArcGis 9,2, Arc View, 3.3, Diva 7.2 and Surfer 12) for storage, interpolation and visualization of the climate scenarios.

The data about temperature and precipitation taken from WorldClim data set was used, with a spatial resolution of about 1 km^2 (WorldClim, 2014).

The GCM output was downscaled and calibrated using WorldClim 1.4 as baseline 'current' climate (1951-2000). HadGEM2-AO (HD) climate change scenarios for the time periods: 2050s (average for 2041-2060) and 2070s (average for 2061-2080) by applying the 4 RCPs were used.

It is very important for the practice to be outlined the different zones in Bulgarian forest map, in which the forest ecosystems will be vulnerable to climate changes. These zones of forest ecosystems at climate changes can be set with climate indices.

In this study, De Martonne (1926) aridity index (IDM) was used, which is applicable locally (Baltas, 2007):

$$IDM = P/(T+10) \qquad (1)$$

where: P is the annual precipitation, mm

T - the annual mean air temperature, °C.

It should be noted that the application of methods of De Martonne, Budiko, Selyaninov and Holdridge yield similar results for Bulgaria (Raev, Alexandrov, 2011).

Climatic classification based on De Martonne aridity index in different forest vulnerability zones is shown in Table 1.

Identification of forest vulnerability zones in Bulgaria was based on data processing in GIS environment. Main source data comprised inventory descriptions of approximately 1.3 million forest sub-compartments. GIS analyses were undertaken on the basis of the initial 8 raster dataset representing De Martonne aridity index for different years and different scenarios. Raster datasets were projected into WGS84 UTM 35N, which is the coordinate system used for the forestry database in Bulgaria. Consequently, raster datasets were reclassified according to the seven vulnerability zones A, B, C, D, E, F and G. After reclassification they were converted into vector feature classes – polygon type. The feature classes were used to perform spatial join in order to attach the corresponding vulnerability zone information to each sub-compartment from the national forestry database. In this way, 8 new feature classes were

Table 1
De Martonne aridity index and forest vulnerability zones

IDM	Climate classification	Forest vulnerability zones	
		Name*	Vulnerability level
10-25	Semi-arid	A	Very high
25-30	Moderately arid	B	High
30-35	Slightly humid	C	Medium
35-40	Moderately humid	D	
40-50	Humid	E	Low
50-60	Very humid	F	
60 -187	Excessively humid	G	From medium to very high

*Zone A: lasting deficit in moisture which leads to destruction of forests; Zone B: lasting disturbances of moisture; Zone C: disturbances of moisture in some years; Zone D: small disturbances of moisture in some years; Zone E: optimal conditions of moisture; Zone F: optimal conditions of moisture; Zone G: gradual deterioration of environmental conditions due to excess of moisture.

derived – each of them containing national forestry database on sub-compartment level and the corresponding information from one of the initial eight raster datasets. Afterwards, the necessary tables were produced, using the summary statistics procedure and several attribute join procedures. The forestry database was received from Executive Forestry Agency, Sofia.

RESULTS

Projected changes of air temperature

In current climate (1951-2000) the annual mean air temperature in lowlands varies from 10 to 14°C (Fig. 2). The average annual temperature for the foothills and mountainous areas is between 4 and 11°C, which depends mainly on the altitude and slope exposure. At the optimistic scenario RCP2.6 the average annual air temperature is expected to increase by 1-2°C in lowlands and 0.5-1°C in mountainous regions in 2050. Probably, in 2070 the increase would be about 2-3°C in lowlands and 1-2°C in mountain areas, compared to the current climate. At the pessimistic scenario RCP8.5 the increase of the air temperature will be even more significant. By 2050 mean temperatures are expected to rise with 3-4°C in lowlands and with 2-3°C in mountain areas, which is a significant increase compared to the current climate. In 2070 the increase of air temperature continues and is expected to be 1°C higher compared to 2050 (Fig. 3). Assuming that by 2050 the air temperature could be between optimistic and pessimistic scenario, warming in the country is expected to be around 0.75-1.5°C (RCP2.6) and 2.5-3.5°C (RCP8.5).

The expected air temperature increases at national level are too close to the

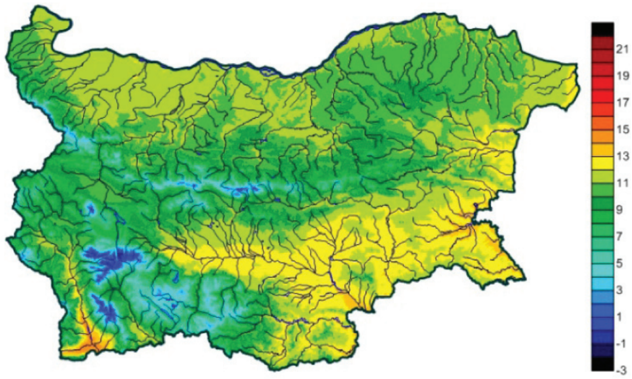

Fig. 2. Annual mean air temperature in current climate (1951-2000)

expected temperatures for the Black Sea countries by other researchers (Lindner et al., 2010). According to the same authors, the annual mean temperature increase is projected to be in the order of 3-4°C in Temperate Continental zone, while in Black Sea region it is expected to be up to 4.5°C to the end of XXI century. These projections are within the range of expected temperatures given in the IPCC AR5 (2014).

Projected changes of precipitation

The annual precipitation in current climate (1951-2000) is shown in Fig. 4. In lowland areas it is between 450 and 650 mm but in the mountains it reaches 1000 to 1100 mm. This corresponds to the precipitation results of current climate 1961-1990 (Koleva, Peneva, 1990).

Significant changes in precipitation are not expected in RCP2.6. For the years of 2050 and 2070, the expectation is for less precipitation in Northeast Bulgaria only (Fig. 5).

At RCP8.5, a significant reduction of precipitation seems to be mainly in Northeast Bulgaria, Dobrudzha, Southwest Bulgaria and Thracian valley. Furthermore, the expected change in the annual precipitation regime is as follows: increase in winter precipitation and reduction of rainfall during the vegetation period, which will be harmful to forest vegetation. The decrease of precipitation is expected to affect the whole country. The zone of climate optimum of the forests at 900-1700 m will be reduced.

Projected changes of De Martonne aridity index and forest vulnerability zones

The vulnerability zone A (IDM 10-25) in current climate (1951-2000) occupies small areas in Northeast Bulgaria, valleys of the rivers Struma and Maritsa and some Black Sea rivers (Fig.6). Zone B (IDM 25-30) covers the largest areas in the plains and hilly part to 500-600 m, with lasting disturbances of moisture. Zone C (IDM 30-35) covers the foothills of the Balkan Mountains, Ludogorie and high

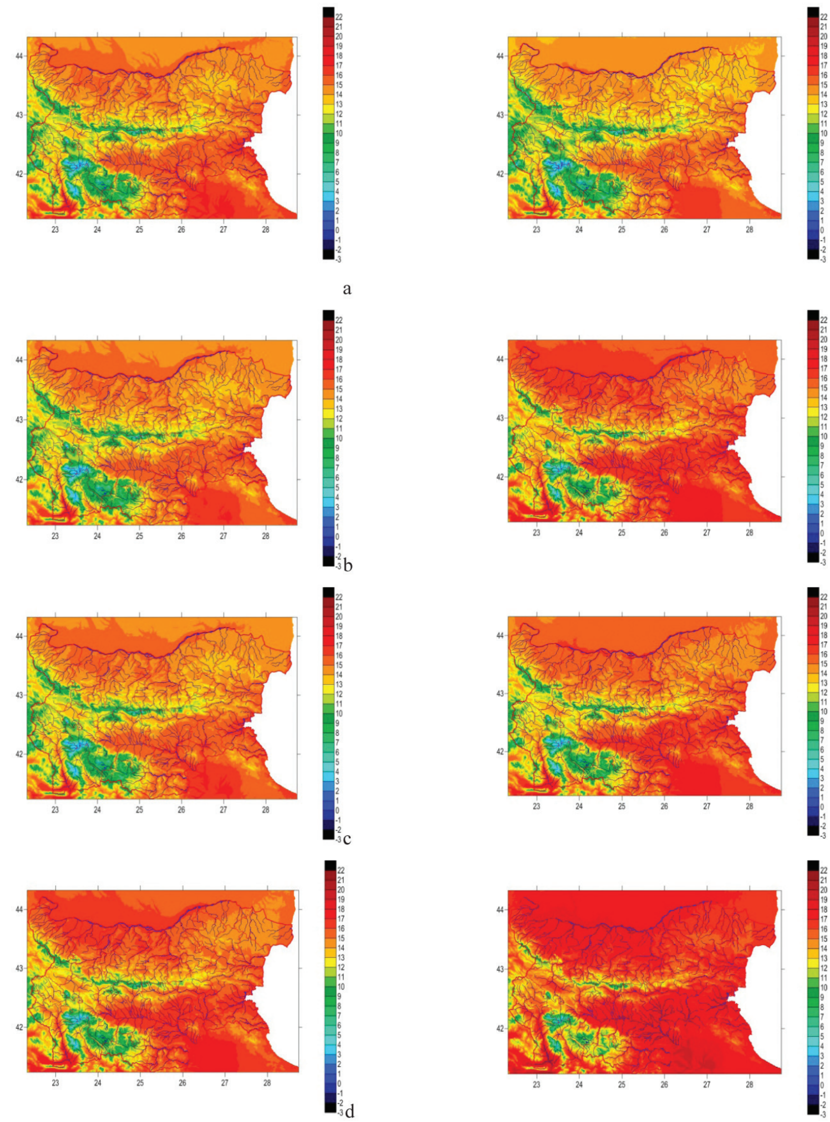

Fig. 3. Projected changes in annual mean temperature (°C) in 2050 (left) and 2070 (right) at RCP2.6 (a), RCP4.5 (b), RCP6 (c), and RCP8.5 (d)

plains. Here the conditions are more favourable. In zone D (IDM 35-40) the forests are of medium vulnerability level with small disturbances of moisture in some years. Zone D covers large areas in the Balkan Mountains and other mountains areas of 700-1000 m. It possesses good conditions for forest development. The forests in zone E (IDM 40-50) are characterized by low vulnerability level with optimal moisture conditions. The zone covers areas from 1000 to 1400 m. Zone F (IDM 50-

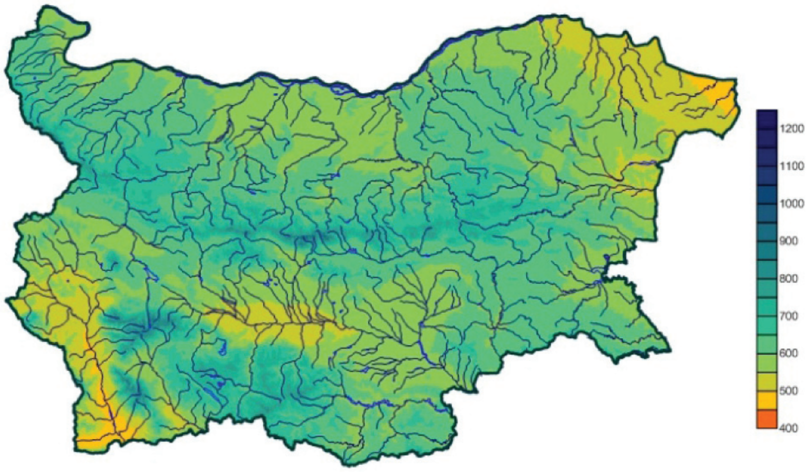

Fig. 4. Annual precipitation in current climate (1951-2000)

60) - low vulnerability level in the belt from 1400 to 1700 m. This zone has optimal environmental conditions for forest development. And finally, zone G (IDM 60-187) is in the high mountains from 1700 to 2925 m.

At the RCP2.6, the zone A is growing mainly in: Northeast Bulgaria, valleys of the rivers Struma and Maritsa, and the Thracian valley (Fig. 7). Zone B covers large areas in North and South Bulgaria and the high fields. The forest areas in other zones C, D, E, F, G will be reduced. At the RCP4.5, the zone A will increase substantially, especially in 2070, covering most of the country. All other zones are expected to decrease. The areas with optimal conditions for forests will be limited. RCP6.0 shows some improvement of the environmental conditions. The most unfavourable zoning is at RCP8.5, which will lead to severe environmental conditions for the forests.

Forest areas in the vulnerability zones

In current climate (1951-2000) most of the forest areas are in vulnerability zones B (31.5%) and C (31.3%) (Table 2). At the optimistic scenario RCP2.6, most of them will be in zone B - 40.8% in 2050, and 37.3% in 2070. At RCP4.5 and RCP6.0, the expected forest areas in zone B will be almost the same - between 31.1% and 41.7%. At the pessimistic scenario RCP8.5, the largest part of the forest areas is expected to fall in zone A - 56.8% in 2050 and 65.6% in 2070, i.e., under the most severe climate conditions (Table 2).

Forest tree species over vulnerability zones

Currently, the total number of forest tree species in Bulgaria is 158, of which 119 are broadleaved and 39 coniferous. Distribution of the areas by tree species and vulnerability zones in 2000 and 2050 (RCP2.6 and RCP8.5) is given in Table 3. The year of investigation is 2000, corresponding to current climate, and the nearest

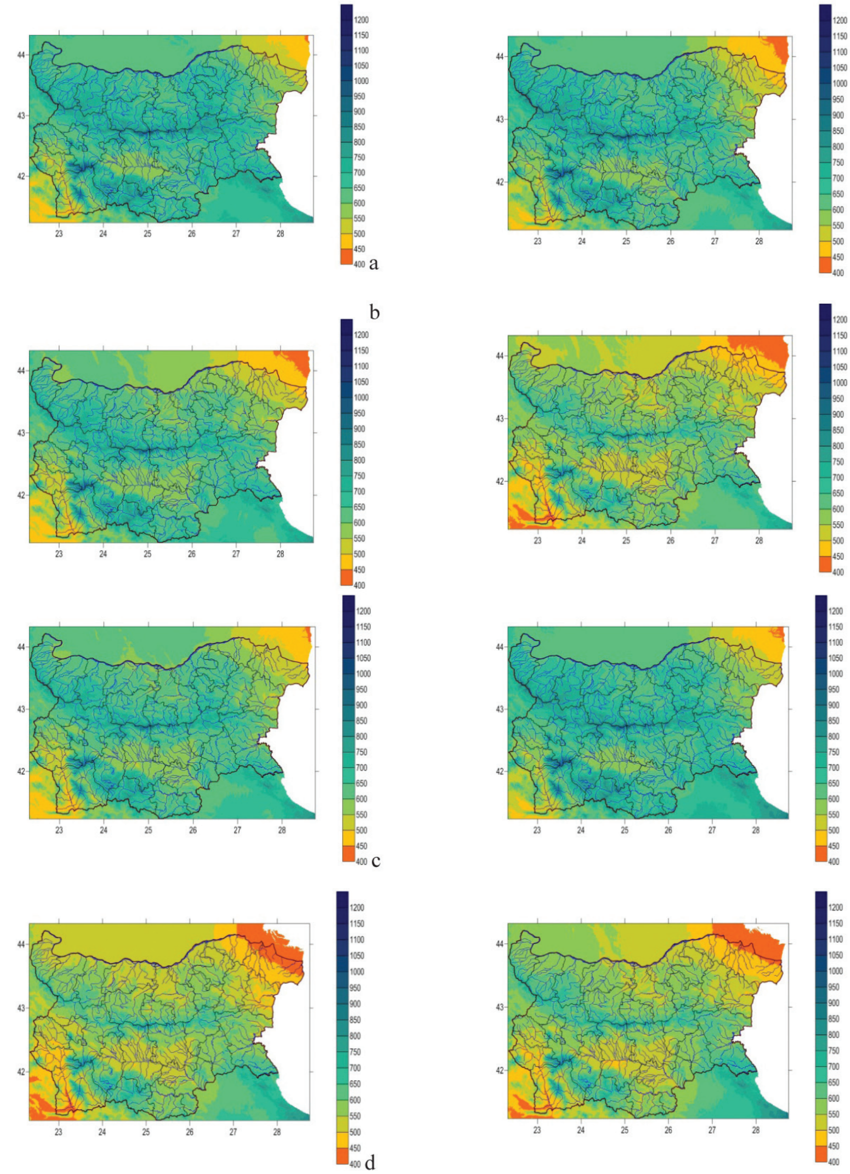

Fig. 5. Projected changes in annual precipitation (mm) in 2050 (left) and 2070 (right) at RCP2.6 (a), RCP4.5 (b), RCP6 (c), and RCP8.5 (d)

future period in 2050, which retains similar trends for the following period to 2070. The area of different tree species in most favourable vulnerable zones D, E and F is compared with the total area of the corresponding tree species.

The most common coniferous tree species is *Pinus sylvestris* L. forming 51.7%

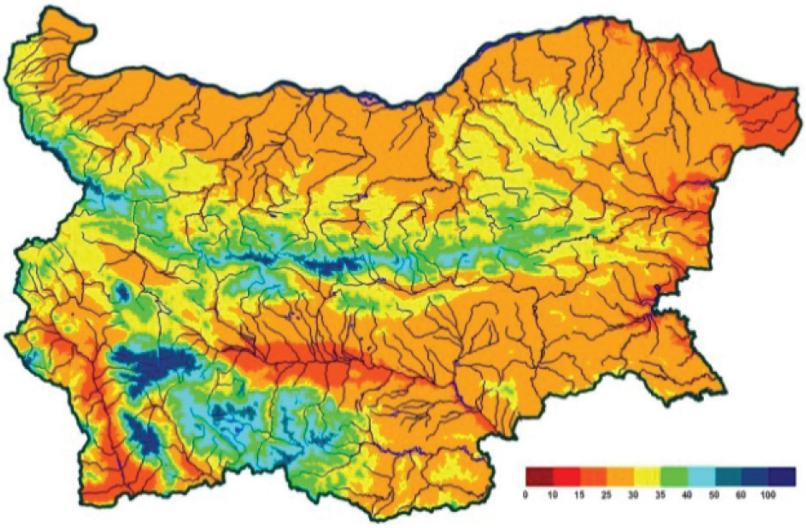

Fig. 6. De Martonne aridity index in current climate (1951-2000)

Table 2
Total forest areas by vulnerability zones in 2000, 2050 and 2070.

Forest vulnera-bility zone	Unit	Current climate	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
		2000	2050	2070	2050	**2070**	**2050**	**2070**	**2050**	**2070**
A	thous.ha	186.6	642.8	685.0	966.7	2200.8	1051.9	845.8	2376.2	2744.7
	%	4.5	15.4	16.4	23.1	52.6	25.2	20.2	56.8	65.6
B	thous.ha	1319.3	1707.6	1561.8	1703.6	1300.6	1694.1	1743.2	1172.5	1001.1
	%	31.5	40.8	37.3	40.7	31.1	40.5	41.7	28.0	23.9
C	thous.ha	1307.4	1069.6	1052.3	879.8	511.8	851.9	943.8	462.6	356.8
	%	31.3	25.6	25.2	21.0	12.2	20.4	22.6	11.1	8.5
D	thous.ha	767.8	510.1	560.9	440.0	142.5	414.7	456.5	143.5	68.3
	%	18.4	12.2	13.4	10.5	3.4	9.9	10.9	3.4	1.6
E	thous.ha	478.1	229.2	290.8	174.8	22.9	156.1	176.8	24.3	9.5
	%	11.4	5.5	7.0	4.2	0.5	3.7	4.2	0.6	0.2
F	thous.ha	109.5	20.2	28.6	15.1	3.1	11.6	13.8	2.7	1.6
	%	2.6	0.5	0.7	0.4	0.1	0.3	0.3	0.1	0.0
G	thous.ha	13.3	2.5	2.7	2.0	0.4	1.7	2.1	0.3	0.1
	%	0.3	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

of coniferous forests, both natural and artificial. Total 60.7% of these forests are part of the most favourable vulnerability zones D, E and F (900-1600 m) in 2000. At the RCP2.6 (2050), the expectation is that the area will decrease to 39.21% in the same

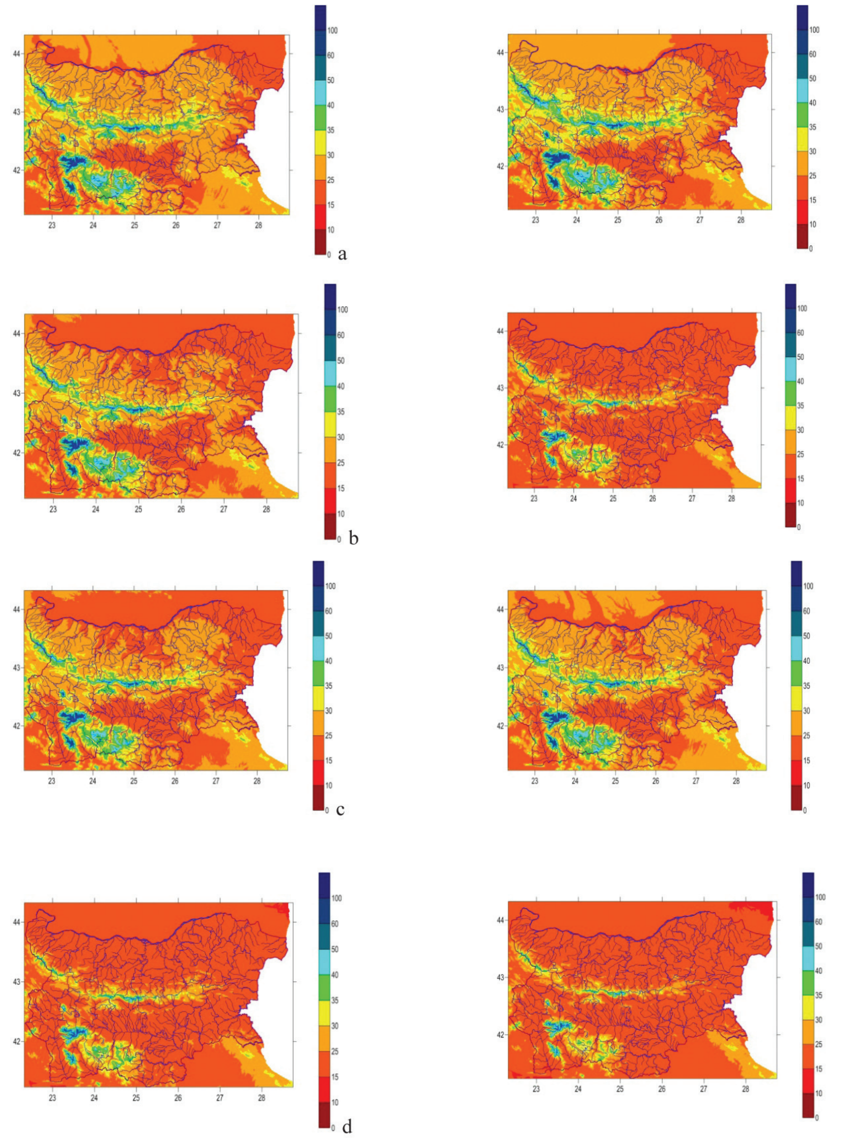

Fig. 7. Projected changes of De Martonne aridity index in 2050 (left) and 2070 (right) at RCP2.6 (a), RCP4.5 (b), RCP6 (c), and RCP8.5 (d)

zones. At the RCP8.5 (2050), 8.3% of Scotch pine forests will be in the favourable zones D, E, F only. Sharp deterioration in water regime can cause catastrophic consequences in the remaining Scotch pine forests in zones A, B and C below 800-900 m (Fig. 8).

The most common tree species of deciduous forests are *Quercus* spp. (Oaks)

Table 3

Distribution of the area of forest tree species over vulnerability zones in 2000 and 2050 (RCP2.6 and RCP8.5).

No.	Year/RCP; Zones	A	B	C	D	E	F	G	D+E+F	*%
Total forest area (3 781 796 ha; 100%)										
1.	2000	151 938,4	1 116 113,3	1 165 224,9	743 262,9	492 424,9	102 989,8	9 841,8	1 338 677,6	35,40
2.	2050, RCP 2.6	530 753,0	1 479 041,9	1 013 214,6	515 870,4	226 106,2	16 167,8	642,1	758 144,4	20,05
3.	2050, RCP 8.5	2 036 490,1	1 116 669,7	474 287,4	131 838,6	21 542,8	932,5	34,9	154 313,9	4,08
Coniferous (1 082 836,2 ha; 28,63% of total forest area)										
1.	2000	20 201,4	178 457,1	267 267,7	236 397,7	296 476,2	75 691,3	8 344,8	608 565,2	56,20
2.	2050, RCP 2.6	74 898,7	290 704,5	288 829,7	255 099,1	159 944,0	12 763,0	597,1	427 806,1	39,51
3.	2050, RCP 8.5	366 538,5	322 824,0	271 039,0	103 084,8	18 492,7	822,8	34,5	122 400,3	11,30
Pinus sylvestris L. (560 085,8 ha; 14,81% of total forest area)										
1.	2000	3 983,2	64 800,4	149 726,2	151 873,7	162 233,3	26 023,6	1 445,5	340 130,5	60,73
2.	2050, RCP 2.6	21 371,6	132 824,0	186 202,6	148 952,2	67 697,6	2 969,2	68,6	219 619,0	39,21
3.	2050, RCP 8.5	153 033,6	208 480,1	151 946,4	42 059,4	4 447,5	118,8	0,0	46 625,6	8,32
Pinus nigra Arn. (277 998,2 ha; 7,35% of total forest area)										
1.	2000	15 905,7	107 965,8	104 861,3	38 058,1	10 496,5	710,9	0,0	49 265,4	17,72
2.	2050, RCP 2.6	50 958,5	147 296,4	62 482,0	14 506,8	2 754,5	0,0	0,0	17 261,3	6,21
3.	2050, RCP 8.5	200 359,2	64 830,1	11 180,2	1 605,6	23,1	0,0	0,0	1 628,7	0,59
Picea abies (L.) Karst. (199 335,5 ha; 5,27% of total forest area)										
1.	2000	115,9	3 277,5	7 251,0	33 285,3	106 498,0	44 222,7	4 685,1	184 006,0	92,31
2.	2050, RCP 2.6	913,9	5 867,8	27 423,2	76 599,2	81 006,6	7 470,4	54,3	165 076,2	82,81
3.	2050, RCP 8.5	7 115,5	34 909,9	91 656,3	53 660,1	11 948,4	45,2	0,0	65 653,8	32,94
Other coniferous (45 416,7 ha; 1,20% of total forest area)										
1.	2000	196,6	2 413,3	5 429,2	13 180,7	17 248,4	4 734,2	2 214,3	35 163,3	77,42
2.	2050, RCP 2.6	1 654,7	4 716,4	12 721,9	15 041,0	8 485,2	2 323,4	474,2	25 849,6	56,92
3.	2050, RCP 8.5	6 030,2	14 603,9	16 256,0	5 759,7	2 073,6	658,8	34,5	8 492,1	18,70
Deciduous (2 698 959,8 ha; 71,37% of total forest area)										

Table 3. Continued.

No.	Year/RCP; Zones	A	B	C	D	E	F	G	D+E+F	*%
1.	2000	131 737,0	937 656,2	897 957,2	506 865,2	195 948,7	27 298,5	1 497,0	730 112,4	27,05
2.	2050, RCP 2.6	455 854,3	1 188 337,3	724 384,9	260 771,2	66 162,2	3 404,8	45,0	330 338,3	12,24
3.	2050, RCP 8.5	1 669 951,6	793 845,7	203 248,5	28 753,8	3 050,1	109,7	0,4	31 913,6	1,18
Quercus spp. (1 315 858,8 ha; 34,79% of total forest area)										
1.	2000	76 438,9	588 008,3	486 508,2	143 628,0	20 506,5	768,9	0,0	164 903,4	12,53
2.	2050, RCP 2.6	270 825,4	728 820,9	275 752,0	37 710,2	2 701,9	48,4	0,0	40 460,4	3,07
3.	2050, RCP 8.5	994 437,7	301 506,4	19 138,6	727,6	48,4	0,0	0,0	776,0	0,06
Fagus sylvatica L. (563 218,6 ha; 14,89% of total forest area)										
1.	2000	1 312,2	19 320,1	128 368,2	244 638,9	143 324,3	24 901,2	1 353,8	412 864,3	73,30
2.	2050, RCP 2.6	7 630,8	65 384,5	252 498,5	176 458,0	58 083,5	3 151,0	12,3	237 692,5	42,20
3.	2050, RCP 8.5	81 581,9	297 823,2	155 603,3	25 493,6	2 685,1	31,5	0,0	28 210,2	5,01
Carpinus orientalis Mill. (239 224,1 ha; 6.33% of total forest area)										
1.	2000	14 655,6	77 238,4	103 244,0	36 541,5	7 329,1	215,4	0,0	44 086,0	18,43
2.	2050, RCP 2.6	38 507,8	121 977,5	64 869,7	12 675,9	1 193,2	0,0	0,0	13 869,1	5,80
3.	2050, RCP 8.5	169 709,7	62 436,0	6 872,4	206,0	0,0	0,0	0,0	206,0	0,09
Robinia pseudoacacia L. (150 041,6 ha; 3,97% of total forest area)										
1.	2000	12 553,7	95 594,7	36 922,1	4 559,0	406,2	5,9	0,0	4 971,1	3,31
2.	2050, RCP 2.6	47 069,1	90 238,7	11 919,3	790,7	23,8	0,0	0,0	814,4	0,54
3.	2050, RCP 8.5	141 477,6	8 228,1	331,5	4,4	0,0	0,0	0,0	4,4	0,003
Carpinus betulus L. (144 254,2 ha; 3,81% of total forest area)										
1.	2000	1 220,4	18 587,5	67 075,9	46 970,4	9 984,8	399,8	15,3	57 355,0	39,76
2.	2050, RCP 2.6	6 841,7	47 423,7	73 113,9	15 519,7	1 308,6	46,6	0,0	16 874,9	11,70
3.	2050, RCP 8.5	68 789,7	67 794,6	7 272,7	360,7	36,3	0,0	0,0	397,1	0,28
Other deciduous (286 362,5 ha; 7,57% of total forest area)										
1.	2000	25 556,1	138 907,1	75 838,7	30 527,5	14 397,8	1 007,3	127,9	45 932,6	16,04
2.	2050, RCP 2.6	84 979,5	134 492,0	46 231,4	17 616,7	2 851,3	158,9	32,7	20 626,9	7,20
3.	2050, RCP 8.5	213 955,0	56 057,4	14 029,9	1 961,5	280,4	78,2	0,4	2 320,1	0,81

*Percentage (%) of the area of forest tree species over vulnerability zones D, E, F according to the total area of the corresponding forest vegetation type

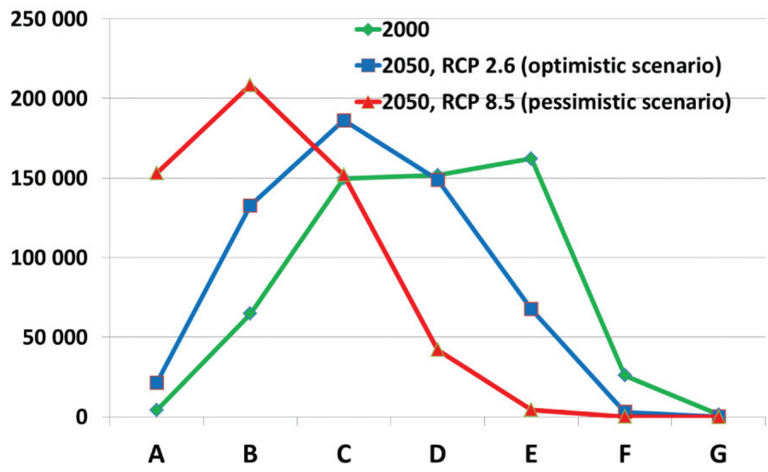

Fig. 8. Distribution of *Pinus sylvestris* L. over vulnerability zones A-G, ha

that builds 48.8% of them. 12.5% of Oaks forests are part of the most favourable vulnerability zones D, E and F in 2000. Part of them grows well in more drought conditions (for example *Quercus pubescens*) and this is the reason that the area of zone C could be added. Therefore, currently 49.5% of Oaks area has not any problems with water supply. At the RCP2.6 (2050), 24% of them will grow in favourable conditions (zones C, D, E, F) only. At the RCP8.5, the forests of *Quercus* spp. are expected to fall in areas with unfavourable environmental conditions and will probably migrate to higher altitudes (Fig. 9).

The second important tree species of the deciduous forests is *Fagus sylvatica* L. (Beach) that builds 20.9% of them. 73.3% of Beach forests are part of zones D, E and F in 2000. The expectation is that 42.2% of them will be in favourable zones at RCP2.6 (2050).

The forests of *Pinus sylvestris* L. (14.8% of total forest area), *Quercus* sp. (34.8%) and *Fagus sylvatica* L. (14.9%) have the most economic and ecological importance for Bulgaria. They cover 64.5% of total forest area. The future expectations for these main tree species are limited by projections RCP2.6 and RCP8.5 and give some ideas how to adapt Bulgarian forests to drought.

DISCUSSION

The results of the present study show clearly that forest ecosystems in Bulgaria currently are subjected to increasing negative climatic influence, and will be subjected in the future, too. There are four zones with highly vulnerable ecosystems: arctic region, mountain regions, coastal zones and various parts of the Mediterranean (WBGU, 2003; EEA, 2006). Bulgarian forests fall in three of these four vulnerability zones: mountains, coastal and Mediterranean. Therefore, the most vulnerable will be

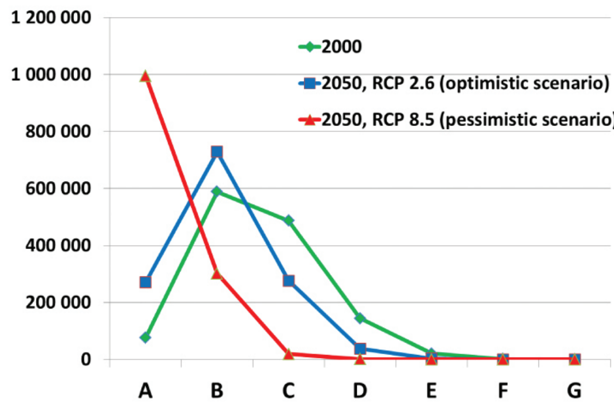

Fig. 9. Distribution of *Quercus* spp. over vulnerability zones A-G, ha

the forest ecosystems in Continental Mediterranean zone, in large part of mountainous forests and particularly, in the plain and hilly areas of the country.

While in the northern half of Europe increase of temperature and precipitation will have positive effect on the forests, in Southern Europe, and particularly in the Mediterranean basin, the expected change will include considerable increase of temperatures and precipitation reduction in the vegetation period (Maracchi et al., 2005; Rio et al., 2005). This was confirmed by the study performed in Bulgaria, Slovenia, Lithuania and Ukraine (GWP CEE, 2015). The negative effect of these climate changes will lead to sharp increase of evapotranspiration, water deficit stress, pathogen and insect attacks, forest fires and threat of destruction of forest communities. The threat is most dangerous for coniferous plantations in the lowermost altitudinal belt in Bulgaria (Raev et al., 1991).

It could be expected that the problems of survival of coniferous plantations of *Pinus sylvestris* L., *Picea abies* (L.) Karst. and *Pinus nigra* Arn. in the lowermost zone in the country will become more expressed during the next decades. This concerns mostly the vulnerability zones A, B and C, i.e. these at altitude from 0 to 800-900 m in Bulgaria, as well as in other countries of the Mediterranean basin, the participation ratio of conifers is expected to decrease and they will be replaced by more drought-resistant broadleaved formations, consisting mainly by *Quercus* species but also representatives of the genera *Acer, Juglans, Sorbus* and some others, mainly on better sites (Hemery, 2008). Currently, the Oaks are facing serious problems on poorer sites (Rossnev et al., 2010).

The evaluation of participation of Beech (*Fagus sylvatica* L.) in the future forests in Europe and in Bulgaria is ambiguous. It is generally accepted it could expand to Western and Central Europe where in many places was replaced artificially by *Picea abies, Pinus sylvestris* and other conifers several centuries ago (Sykes, Prentice, 1996; Bolligger, 2002; Koling et al., 2007). Other researchers claim that problems with the tolerance of beech ecosystems could arise in the southern part of Central Europe, where temperature is expected to increase by about 2°C and the frequency of drought periods will increase until 2050 (Gessler et al., 2007). For the conditions of Bulgaria it could be accepted that within the zone 900-1600 m they will not be seriously affected. More pronounced will be the treats for the zone 500-900 m, particularly during the drought periods.

For the forests of Temperate climate zone of Europe, incl. for Bulgarian ones, the researchers propose designing of special programmes of measures for their adaptation to future climate change and for introducing of new, close-to-nature, forest management. The application of these measures is expected to increase forest tolerance and their survival in the future unfavourable climate change (Mason et al., 1999; Schutz, 1999; Stephenson, 2001; Seppala et al., Eds.), 2009; Raev et al., 2011).

CONCLUSIONS

Studies on the information used about the temperature, precipitation and the new scenarios of IPCC AR5 (2014) and WorldClim data set (2014), as well as the investigation on area distribution of 1.3 million forest sub-compartments and tree species over 7 forest vulnerability zones in Bulgaria, allow the following **conclusions**:

a) In current climate (1951-2000), most widely distributed forest areas with mean annual air temperature from 11°C to 4°C at altitude from 500-600 to 1600-1800 m had temperate and cool mountain climate;

b) In 2050 the warming in the country is expected to be between 0.75 and 1.5°C (optimistic scenario RCP2.6) and 2.5-3.5°C (pessimistic scenario RCP8.5), but in 2070 would be higher - between 1.5-2.5 °C (RCP2.6) and 3.5-4.5 °C (RCP8.5) in 2070;

c) Precipitation in current climate (1951-2000) increased from 450 to 500 mm in the lowlands and 1000-1100 mm in the high mountains. Precipitation in the optimum forest climate zone from 900 to 1700 m is 720-1100 mm;

d) At the RCP 2.6 in 2050-2070, no major precipitation changes are expected. At the RCP 8.5 for the same period, precipitation reduction with 100-200 mm is expected. There is a change in the annual course of precipitation: reduction of rainfall during the growing season and increased precipitation in the cold part of the year;

e) In current climate most forests (63.7% of the area) fall in zones C, D, E, F i.e. under more favourable vulnerability zones. 36.3% of the forest areas are in unfavourable zones A, B and G. At the RCP2.6, the expectation is about 53.8-56.3% of the forest area in 2050-2070 to fall in unfavourable vulnerability areas. At the RCP8.5, the rate of unfavourable vulnerability zones will increase to 84.8% in 2050 and 89.5% in 2070;

f) In current climate Bulgarian forests are formed by 159 tree species, of which 119 deciduous and 39 coniferous. The most common tree species (*Quercus* sp., *Fagus sylvatica* L., *Pinus sylvestris* L.) ocuppy 64.5% of the forest area;

g) The forest formations of the group *Quercus* spp. are widely distributed from 0 to 1200 m. At current climate about half of them fall in zone A and B. In 2050-2070 more hygrophytes and more productive oaks probably will have serious problems and migration to higher altitude as a result of the expected drought is possible;

h) In current climate 96% of the forests of *Fagus sylvatica* L. are in favorable vulnerability zones for them (C, D, E, F) - from 700 to 1600 m. It is expected that the climate conditions at higher altitudes would not be changed seriously in 2050-2070 but at low altitudes *Fagus sylvatica* L. will be at risk in drought periods;

j) In current climate 61% of *Pinus sylvestris* L. growing at optimal forest climatic conditions but 39% of them are located in areas from sea level to 700-900 m. The expected drought from 0 to 900 m in 2050-2070 will decrease these tree species, introduced outside of its natural habitat.

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