Integrated Drought Management Programme
in Central and Eastern Europe

Assessment of drought impact on forests

Milestone no.3

Elaboration of maps for current climate, 2050 and 2070 in Bulgaria, Lithuania, Slovenia and Ukraine (pilot area) and determination of forest vulnerability zones

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Name of the milestone:	**Milestone 3:** Elaboration of maps for current climate, 2050 and 2070 in Bulgaria, Lithuania, Slovenia and Ukraine (pilot area) and determination of forest vulnerability zones
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ACRONYMS

a.s.l.	above sea level
AR5	Fifth Assessment Report
CEE	Central and Eastern Europe
EEA	European Environment Agency
EC	European Commission
EU	European Union
GCM	Global climate model
GWP	Global Water Partnership
GWP CEE	Global Water Partnership for Central and Eastern Europe
IDM	De Martonne aridity index
IDMP	Integrated Drought Management Programme
IPCC	Intergovernmental Panel on Climate Change
RCP	Pepresentative concentration pathway
SOER	State of the Environment Report
UN	United Nations
WMO	World Meteorological Organization

Content

1. INTRODUCTION

Climate change is shifting the world's climate zones as the planet warms. As this occurs, commercial and native tree stands are becoming standed in climate zones with less than optimal growing conditions. Forest ecosystems in Europe are very likely to be strongly influenced by climate change and other global changes (Shaver et al. 2000, Blennow and Sallnäs. 2002, Askeev et al. 2005, Kellomäki and Leinonen. 2005, Maracchi et al. 2005, IPCC. 2007). Warmer, drier conditions will lead to more frequent and prolonged droughts, as well as to a longer fire season and increased fire risk (IPCC. 2007).

Identification of measures for the forests to adapt to negative effects of drought in four GWP CEE countries (Bulgaria, Slovenia, Lithuania and Ukraine – pilot area) is the main objective of demonstration project „Assessment of drought impact on forests". Forest demonstration project corresponds to the Goal 15 „Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertication, and halt and reverse land degradation and halt biodiversity loss" of UN Open Working Group proposal for Sustainable Development Goals. By 2020, protection and restoration of water-related ecosystems, including mountains and forests should be integrated into the United Nations development agenda beyond 2015.

The total forested area in Bulgaria, Slovenia, Lithuania and Ukraine is about 35% of forest areas in GWP CEE region. The high variability of relief, climate and vegetation is the main reason of different forest conditions over vulnerability zones of four countries. Main conclusion of Milestone 1 is that most significant threats, challenges and opportunities for development of the forest sector in those countries depend on drought which influence on forest living conditions.

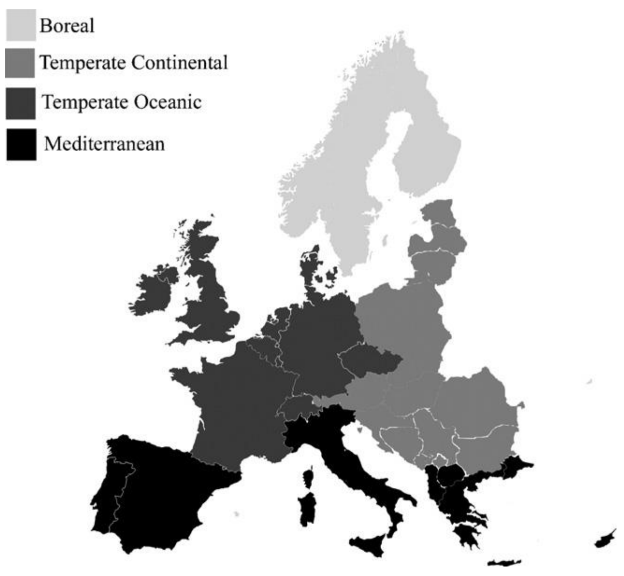
The goal of Milestone 3 is to define the forest areas of vulnerability zones by drought in current climate 1950-2000, 2050 and 2070 and tree species distribution over vulnerability zones in Bulgaria, Slovenia, Lithuania and Ukraine (pilot area). The methodology is adopted in Milestone 2. WorldClim dataset, HadGEM2-AO (HD) and four representative concentration pathways (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) are used for detemination of main drought indices (temperature and precipitation) (WorldClim. 2014, IPCC. 2014). RCPS are the most recent projections of GCMs in Fifth Assessment Report of IPCC. The aridity index of De Martonne is chosen for determination of forest vulnerability zones (De Martonne. 1925).

Determination of the vulnerability forest zones is important for the forestry practice in Bulgaria, Slovenia, Lithuania and Ukraine (pilot area) as these determine the type of drought adaptation/mitigation measures, i.e. the main output of Milestone 3 is a base of next Milestone 4 with programmes of forests measures in expected drought.

2. DROUGHT IMPACT ON FORESTS

GWP CEE region is in temperate continental bioclimatic zone (Figure 2.1) (Lindner et al. 2010).

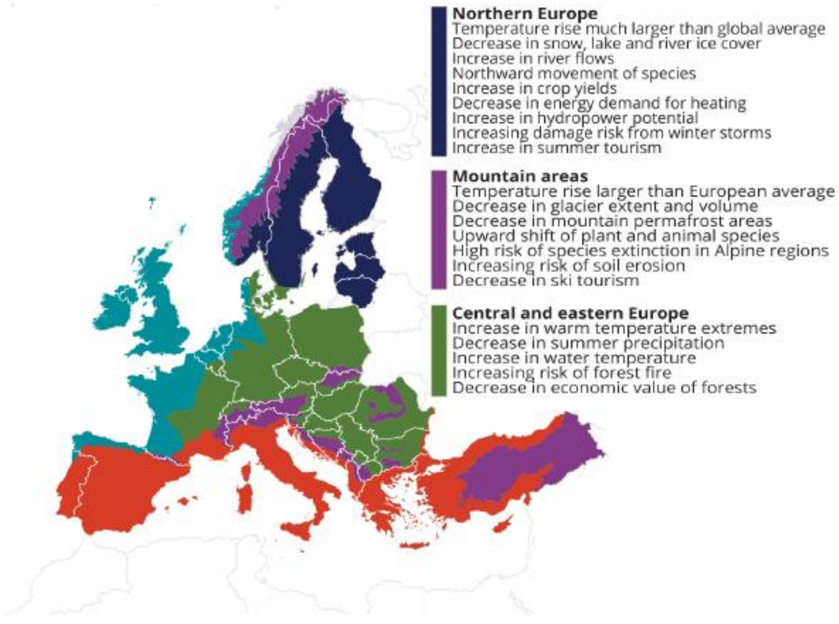
Figure 2.1. Map of European bioclimatic zones.



The annual mean temperature increase in temperate continental bioclimatic zone is projected to be in the order of 3–4^{0}C and up to 4.5^{0}C in the Black Sea Region in 2100 (Lindner et al. 2010). Annual mean precipitation is expected to increase by up to 10% mainly in winter, while summer precipitation is projected to decline in several areas (up to - 10%). In this bioclimatic zone, forest production is mainly constraine by water availability and decreasing annual precipitation or changes in inter- and intra-annual distribution will result in stronger water limitations than today. Production is likely to decrease at sites vulnerable to water stress and to increase where the increased evaporative demand under the elevated temperature is balanced by an increase in precipitation. Impacts on individual species can be either positive or negative, depending on site conditions and regional climatic changes. Rising temperatures without an increase in precipitation or with decreasing precipitation can lead to drought, especially in Mediterranean and temperate continental conditions. Drought conditions reduce forest growth in sensitive species and will effect the species composition of forests (Lindner et al. 2010).

Projected drought impacts on forests (temperature rise, descrease in precipitation and snow, increasing risk of fire and decrease in economic value) are shown in Figure 2.2 (EEA. 2015).

Figure 2.2. Key observed and projected impacts from climate change for the main regions in Europe.



Source: EEA (2012), Climate change, impacts and vulnerability in Europe 2012. An indicator-based report, EEA Report No 12/2012, European Environment Agency.

In Western and Central Europe, the coniferous forests might be affected by warmer climate (Kienast et al. 1998, Maracchi et al. 2005, Koca et al. 2006, Kutnar and Kobler. 2007 and 2011, Ogris and Jurc. 2010) and a significant share of coniferous forests might be replaced by forests mainly dominated by deciduous trees. Abiotic hazards for forests are likely to increase, although expected impacts are regionally specific and will be substantially dependent on the forest management system used (Kellomäki and Leinonen. 2005).

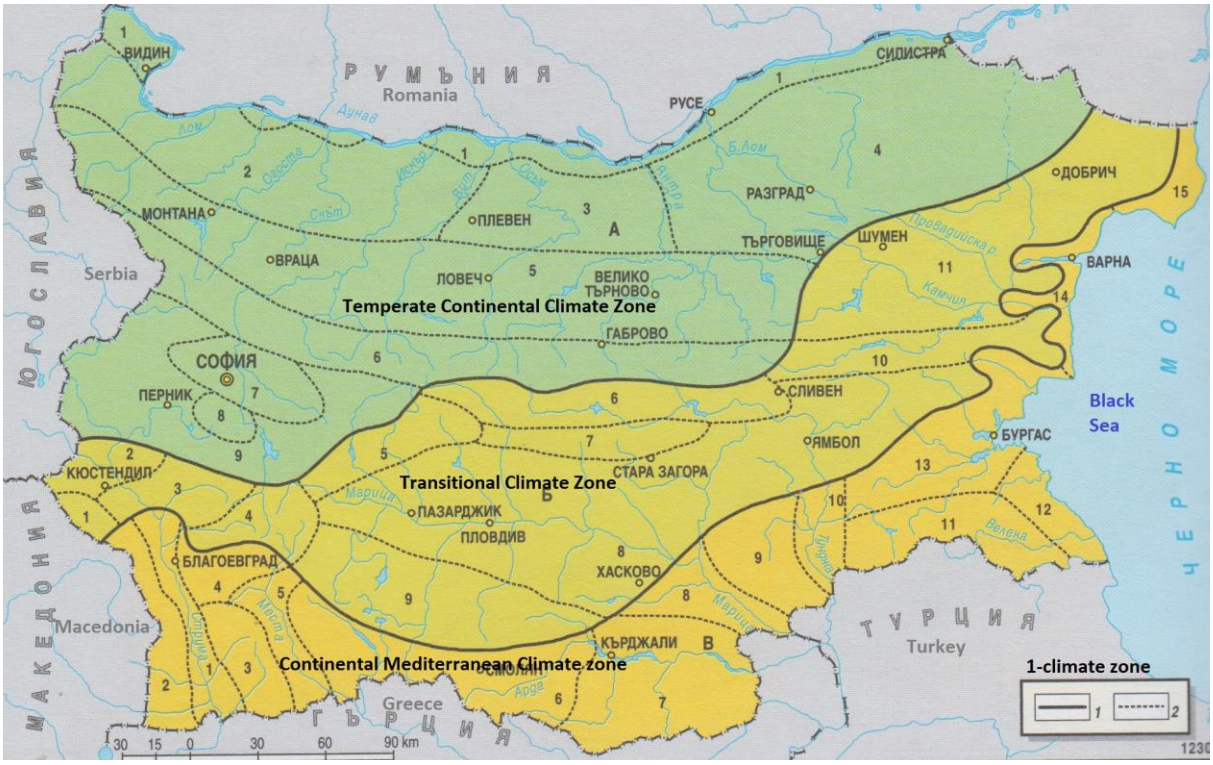
Negative impacts of drought on deciduous forests are also possible (Broadmeadow et al. 2005). Nowadays, the most abundant and dominant tree species of the potential natural vegetation of Central Europe is European beech (*Fagus sylvatica*) (Ellenberg. 1996). It is one of the ecologically and economically most important forest tree species presently supported by forest management in this area (Geßler et al. 2006). The beech forests are likely to be threatened, owing to beech sensitivity towards low water availability (Ellenberg. 1996) and longer drought periods (Fotelli et al. 2002). The physiological performance, growth and competitive ability of European beech may be adversely affected by such changing climate conditions (Peuke et al. 2002, Geßler et al. 2006, Kutnar and Kobler. 2011).

A shift upward of the treeline by several hundred metres caused by climate change could be expected in the future (Badeck et al. 2001, Grace et al. 2002, Kutnar and Kobler. 2011). There is some evidence that this process has already begun in some regions (Mindas et al. 2000, Kullman. 2002, Camarero and Gutiérrez. 2004). The shift upward of woodlands was simulated with different GIS models, and the change of treeline together with the effect of abandonment of traditional alpine pastures is predicted for the Alps (Guisan and Theurillat. 2001, Dirnböck et al. 2003, Dullinger et al. 2004, Kutnar and Kobler. 2011).

2.1.Bulgaria

There are three climate zones in Bulgaria (Figure 2.3) (Velev. 2002, Penin. 2007).

Figure 2.3. Climate zones in Bulgaria (Source: Velev. 2002).



Temperate continental zone in Bulgaria is characterized with cold winters and warm summers, i.e. large annual temperature amplitude. There are well-developed spring summer maximum and winter minimum of precipitation (Penin. 2007). Transitional zone is characterized with warm summers and mild winters. Temperature amplitude is smaller. Precipitation has two maximum (May-June and November-December) and two minimum in August and February. Annual precipitation is almost identical to temperate continental precipitation, but the difference is in their seasonal distribution. Continental Mediterranean area is characterized by warm summers and mild winters, small temperature amplitude and autumn-winter maximum of precipitation, associated with the activity of the Mediterranean cyclones.

The forests in Bulgaria are the most widespread in areas with annual mean temperature of 11^{0}C to 4^{0}C at elevation from 500-600 to 1600-1800 m a.s.l., i.e. in the conditions of temperate and cool mountain climate. Precipitation is 720-1000 mm in the optimum forest climate zone which is at 900-1700 m a.s.l. (Raev. 1983).

After warming in the period 1982-1994, 18.5% of Austrian pine and Scotch pine in lowland forest zones diebacked. The main reason was not only the significant reduction of precipitation but also that these new stands were afforested outside their natural habitat - below 800 m elevation (Raev et al. 1995, Raev et al. 1996, Grozev et al. 1996, Raev. 2001, Knight, Raev, Staneva (edrs.). 2004).

The territories with high and very high range of fire risk occupy totally 51,35% of the country‘s forest area. In these territories 63,72% of the fires appear and the burned down area presents 81,59% of the total burned down area (Georgiev. 2011). Statistical data show that over two-third of the burned forests were conifer stands, planted out of their natural habitat.

2.2. Slovenia

Slovenia is a transitional climate area between the Mediterranean Sea, the Alps, the Dinaric Mountains and the Pannonian Basin. As a consequence, its climate displays wide local climatic variability and fairly large gradients (Ogrin. 2004).

Air temperature changes until now

Slovenia's climate is extremely diverse. Near the coast, the prevailing type of climate is sub-Mediterranean, in mountains Alpine, while the continental climate prevails in the flat parts of eastern Slovenia (Česen & Kranjc. 2006).

From the middle of the 1980s on, above-average warm years have been very common, and the majority of the warmest years starting from the middle of 19th century occurred in the last few years. Also the summer heat waves have been appearing earlier, usually as soon as the end of spring. The summer of 2003 was extremely hot (Česen & Kranjc. 2006).

During the period 1951–2007, mean annual temperatures in Slovenia have increased significantly by 0.15 to 0.29°C per decade (De Luis et al. 2014). Seasons show different trends:

- Spring and summer: A significant increase of 0.3-0.4°C per decade was observed in extended areas of central and north-eastern Slovenia.
- Autumn: No significant trends were observed over most of the Slovenian area.
- Winter: A significant increase of 0.2–0.3°C/decade was observed in central and north-eastern parts of Slovenia.

The strong warming in summer and spring, that is almost twice the trend observed in neighbouring countries, could be enhanced by shalow soils getting dryer due to decrease in winter precipitation in Slovenia (De Luis et al. 2014).

Precipitation changes until now

The maximum annual precipitation is in the northwest in the Julian Alps, where annual precipitation can exceed 3000 mm. On the coast, the annual precipitation usually does not reach 1000 mm, increases towards the top of the Alpine-Dinaric mountain ranges, and then decreases with the increasing distance from the sea towards the northeast. In the extreme northeast the precipitation is usually below 800 mm per year (Česen & Kranjc. 2006).

The spatial distribution of annual precipitation is mainly caused by humid air masses from the Mediterranean, which moves with south-westerly flow towards the mountain barrier. The flow is perpendicular to the orographic barrier and is therefore forced to lift, which causes heavy precipitation events (De Luis et al. 2014). Annual precipitation increases with altitude, at an average rate of 56 mm every 100 m. Such influence of altitude is higher in autumn, lower in winter and intermediate in spring and summer (De Luis et al. 2014).

In European terms, Slovenia is among the areas with the highest number of storms. Each year these include several severe thunderstorms, during which more than 100 mm of precipitation may fall within one hour. Extreme daily precipitation may exceed 400 mm in the Posočje region. In 2005, torrential flooding caused major local damage on several occasions due to the intensity of precipitation (Česen & Kranjc. 2006).

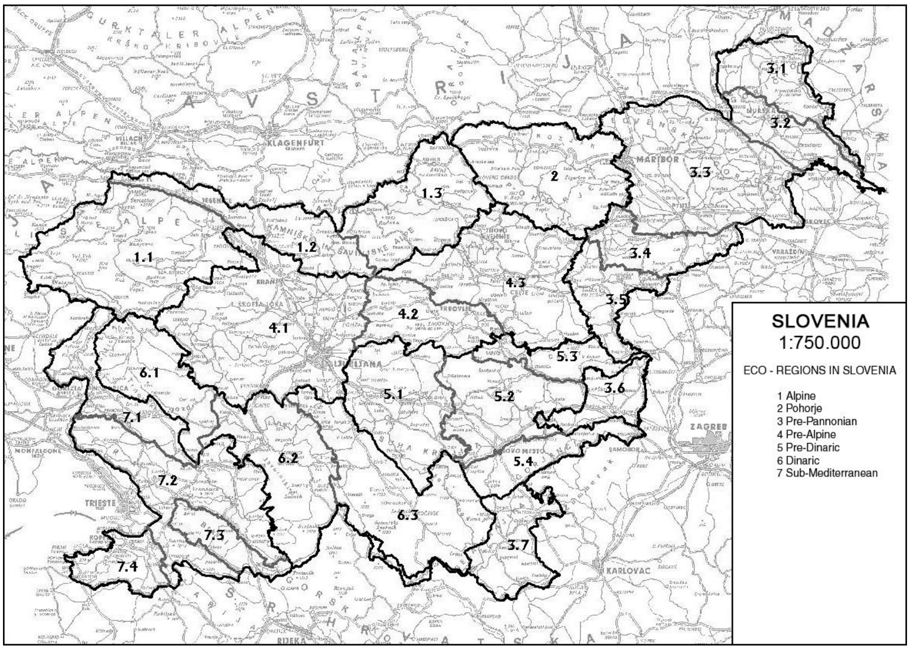
During the period 1951–2007, changes in mean annual precipitation were observed only in the north-western part, where precipitation decreased at a rate of 3–6% per decade (De Luis et al. 2014).

Observed trends for the seasonal precipitation are:

- Spring and summer: Significant trends were observed in the western part of Slovenia only: a decrease of 3–6 % of precipitation per decade.
- In autumn: Trends were non-significant throughout Slovenia.
- Winter: Precipitation significantly decreased by 3–12% per decade; this trend was especially intense in the north-western part of Slovenia.

Based on studies of the phyto-geographic regions and on different geographic features such as geology, soil, relief, precipitation, temperature, potential vegetation, climate, and phenology, the country is divided into the following eco-regions: Sub-Mediterranean, Dinaric, Pre-Dinaric, Alpine, Pre-Alpine, Pohorje and Pre-Pannonian eco-region (Kutnar et al. 2002, Mavsar et al. 2005) (Figure 2.4).

Figure 2.4. Eco-regions in Slovenia (Kutnar et al. 2002).



The occurrence and the structure of the forests are therefore, to a great extent, shaped by the climate, parent rocks, soils and relief. The macroclimatic types are influenced by the Mediterranean Sea, Alpine mountain chain and Pannonian plain. The warm sea-climate, penetrating from the coast, generally reaches the western Slovenian border where it is stopped by the first slopes of the hilly Sub-Mediterranean interior and modified into the cool littoral climate. Highlands, such as the Julian Alps, the Karavanke and the Kamnik-Savinja Alps are characterized by a temperate sub-polar climate. A transition from the Sub-Mediterranean climatic zone to the continental zone is interrupted by the Dinaric mountain massif, which is characterized by an interferential climate. A large part of central Slovenia has a humid continental climate. However, when approaching the Pannonian plains, the climate changes rapidly, and becomes semi-arid continental.

In most recent modelling iteration, supported by research project “Adaptation of forest management to climate changes in relation to expected changes of forest traits and forest spatial changes”, experts predict significant alterations in potential forest stand species composition and potential vegetation in Slovenia under different climate change scenarios. At the end of the century, according to investigated models, the growing stock of the three structurally most important tree species (*Picea abies, Abies alba and Fagus sylvatica*) and present dominant forest vegetation will potentially be reduced. Under the pessimistic scenario almost total decline of *Picea abies* and *Abies alba* is potentially forecasted. Some warmth-tolerant tree species, e.g. invasive species *Robinia pseudoacacia,* will increase significantly. By the end of century, a decrease of the area of Dinaric fir-beech forests (*Omphalodo-Fagetum*) has been forecasted (Kutnar and Kobler 2007, 2011a, 2014, Kutnar et al. 2009). According to the most pessimistic hot-and-dry scenario and assuming that the actual ecological niche of this vegetation type would not be changed in the future, this forest type might disappear completely from territory of Slovenia by the end of the 21st century.

2.3.Lithuania

In Eastern Europe climate change projections suggest that the warming will be greatest in winter. The temperature changes are coupled with increases in mean annual precipitation in northern Europe and decreases in precipitation further south. The annual mean temperature increase is projected to be in the order of 3–4°C. Annual mean precipitation is expected to increase by up to 10% mainly in winter, while there would be reductions in summer precipitation in several areas (up to –10%). The elevated temperature leads to increased evapotranspiration and the demand of water increases. Also milder winters may reduce winter hardening in trees, increasing their vulnerability to frost. Changes in temperature and precipitation in continental and central Europe will lead to a decrease in growth of conifers due to water limitations by the end of the century.

The most important effects of climate change on temperate forests will probably be mediated through changes in frequency of forest fires, wind throws, outbreaks of the spruce bark beetles and pest insects (Report to EC DG ARD. 2008).

At the end of 20th and the beginning of 21st centuries era marked with the frequent extreme droughts in Lithuania and their length was longer than that of the beginning of century. That also was the main cause of the increased number of forest fires (Rimkus et al. 2011, 2013; Sakalauskiene and Ignatavicius. 2003). The increased dryness of spring and summer months during last three decades plays the main negative role for the growth rate of Norway spruce (Vitas. 2003)

2.4. Ukraine (pilot area)

Ukraine has a mostly temperate continental climate, only in the southern Crimean coast climate is humid subtropical. The pilot area is located in temperate continental climate in the north-east of Ukraine, on the plain part and consists of 3 regions: Sumy, Kharkiv and Lugansk. At this territory three natural climatic zones are represented: Forest zone (Polissya - northern part of the pilot territory), Forest steppe zone (central part) and Steppe zone (zone of ravine forests) (at the south-east).

Forest vegetation is represented at the whole pilot territory, but natural forests mostly grow in forest zone (Polissya) and in forest steppe zone. While in steppe the major of forests are artificial and outside their natural habitat.

Polissya – is temperate warm zone with annual precipitations range from 596–760 mm, the probability of droughts is under 10%. In forest-steppe zone annual precipitation level is lower (575-650 mm), the probability of droughts is about 15-40%. In steppe zone there is water deficit (precipitations varies from 350-540 mm) and there is rather big probability of drought – about 40-70% (Adamenko, 2014).

Climate warming is observed in Ukraine since 1989. During last century the average annual air temperature increased by 0.9^{o}C. The highest annual temperature value was registered in 2007 – it exceeded the temperature norm by 2-3^{o}C (Adamenko, 2014). During last two decades in Ukraine there were 11 droughts: in 1992, 1994, 1996, 1999, 2000, 2002 (in Crimea), 2003, 2005 (second half of the year), 2007, 2009 (at Bukovina), 2010; three from them severe – in 2003, 2007, 2010 (Savchuk, 2014). Also heat wave episodes were registered in Eastern Ukraine in first decade of XXI century (Shevchenko et al. 2014).

According to the forest monitoring data in 2003 significant increasing of average defoliation of all tree species caused by drought and foliage browsing insect outbreaks was observed. In 2007 the maximum area of forest fires was registered, the majority of them were in steppe zone (State statistics).

3. METHODOLOGY FOR DETERMINATION OF FOREST VULNERABILITY ZONES

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. (EC. 2013). The focus in forest demonstration project is on main climate change effect – meteorological drought. Meteorological drought is specific to different regions. Meteorological drought is already in progress in 4 GWP CEE, and its effects are being felt in increasing the air temperature and reducing precipitation.

The vulnerability zones of the forest ecosystems are defined in Bulgaria, using the aridity index of De Martonne, Budiko, Selyaninov, and the Holdridge life zones, depending on the climate scenarios for the air temperature and precipitation in 2020, 2050 and 2080. It is found that for the purposes of the forestry production the most appropriate for usage is the aridity index of De Martonne (Raev et al. 2011).

This aridity index is only applicable locally (Baltas. 2007). A measure of aridity of a region, proposed by De Martonne (1925), is given by the following relationship:

$$IDM = P/(T+10) \qquad (3.1)$$

where: P is the average annual precipitation, mm

T - the average annual air temperature, ^{0}C

Climatic classification based on De Martonne aridity index in different forest vulnerability zones is shown in Table 3.1.

Table 3.1. De Martonne aridity index and 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

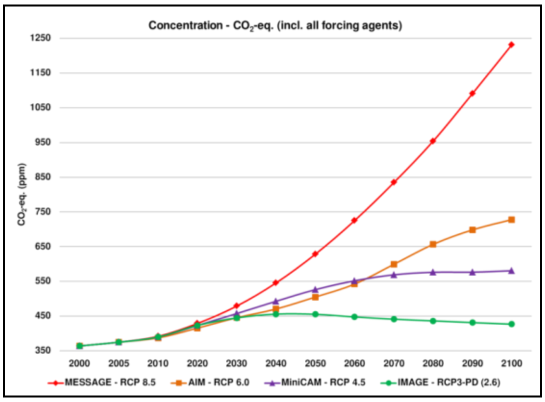
*Zone A: lasting deficit in moisture which leads to destruction of the forests; Zone B: lasting disturbances of the moisture; Zone C: disturbances of the moisture in some years; Zone D: small disturbances of the moisture in some years; Zone E: optimal conditions of the moisture; Zone F: optimal conditions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

WorldClim data were used for annual mean temperature and annual preciptation and climate projections. This is a set of global climate layers/grids with a spatial resolution of about 1 km^2. This data set is freely available for academic and other non-commercial use. One can download climate data for:

- Current conditions (interpolations of observed data, representative of 1950-2000);
- Future conditions: downscaled GCM data from IPPC AR5.

The data available are climate projections from GCMs for four RCPs. These are the most recent GCM climate projections that are used in the Fifth Assessment IPCC report (Figure 3.1) (IPCC AR5. 2014, IPCC. 2014).

Figure 3.1. Representative Concentration Pathways RCP2.6, RCP4.5, RCP6.0, and RCP8.5.



RCPs describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. 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 used in forest demonstration project assuming that RCP8.5 is a pessimistic scenario and RCP2.6 is an optimistic scenario. The GCM output was downscaled and calibrated using WorldClim 1.4 as baseline „current“ climate. HadGEM2-AO (HD) climate change scenarios for the time periods: 2050 (average for 2041-2060) and 2070 (average for 2061-2080) by applying the 4 RCPs were used.

For the purpose of map intersection and statistics the local experts re-projected all maps into the national coordinate system. The raster resolution of all maps is 1 km^2.

GIS - methods used the data from 1.3 million forest sub-compartments when processing the forest vulnerability zones in Bulgaria. GIS analysis were undertaken on the basis of the initial 8 raster dataset representing De Martonne 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 classes – polygon type. The 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 classes were 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 by Executive Forestry Agency, Sofia.

GIS analysis in Slovenia was done similarly as in other three countries. Experts used ArcGIS to reproject WorldClim dataset into the local Slovenian Gauss-Krueger coordinate system. The De Martonne aridity index maps were computed according to scenarios using Idrisi GIS tools, where also the reclassification into vulnerability zones was performed. Finally the reclassified maps were spatially intersected with the raster map of forest types of Slovenia (Kutnar and Kobler.2014) in order to compute the areas of forest types per vulnerability zone in 2050 and 2070 according to different scenarios.
In order to process forest vulnerability zones in Lithuania, GIS based analysis was performed using ArcGIS 10.1 software. All initial raster dataset of De Martonne index was reclassified according to seven vulnerability zones (A, B, C, D, E, F and G) and then converted into polygons (vector classes). By combining these polygons with Lithuanian forestry database using spatial join feature, it was possible to calculate summary statistics and other necessary values. Lithuanian forestry database (forest resources database) was developed on the basis of Lithuania satellite image map 1: 50000 vector database (LTDBK50000V).
GIS-methods were used for determination of climatic factors influence on forests vulnerability in Ukraine also. The GIS of current climate (1950-2000) and modeled climate represented by De Martonne index was combined with forestry borders of the pilot territory. Climate data was generalized at forestry level, due to poor quality of detailed forest GIS of the territory. Forest taxation data base on 2011 (generalized at level of forest compartments) was used as data source. The unit of data analysis was forest compartment, contained IDM values and classes of climate (in current climate and modeled) and present forestry characteristics.

4.RESULTS and DISCUSSIONS

4.1. Air temperature

4.1.1.Bulgaria

In current climate (1950-2000) the average annual air temperature in lowland is from 10^0C to 14^0C (Figure 4.1). The average annual temperature for the foothills and mountainous areas is from 4^0C to 11^0C, which depends mainly on the altitude and exposure of the slopes. At the optimistic scenario RCP2.6 the average annual air temperature is expected to increase by 1^0C -2^0C in lowland and 0.5^0C -1^0C in mountainous regions in 2050 (Figure 4.2). Probably, in 2070 the increase would be about 2^0C -3^0C in lowland and 1^0C -2^0C in mountain areas compared with current climate. At the pessimistic scenario RCP8.5 the increase of the air temperature is even more significant (Figure 4.2). By 2050, average temperatures rise with 3^0C -4^0C in lowlands and with 2^0C -3^0C in mountain areas, which is a significant increase compared to current climate. In 2070 the increase of air temperature continues - 1^0C more comparing to 2050.
Assuming that by 2050 the air temperature could be between optimistic and pessimistic scenario, warming in the country is expected to be around 0.75^0C-1.5^0C (RCP2.6) and 2.5^0C -3.5^0C (RCP8.5).
The expected air temperature increases at national level are too close to the expected temperatures for the Black Sea countries by other researchers (Lindner et al. 2010).

Figure 4.1. Annual mean air temperature in current climate (1950-2000) in Bulgaria.

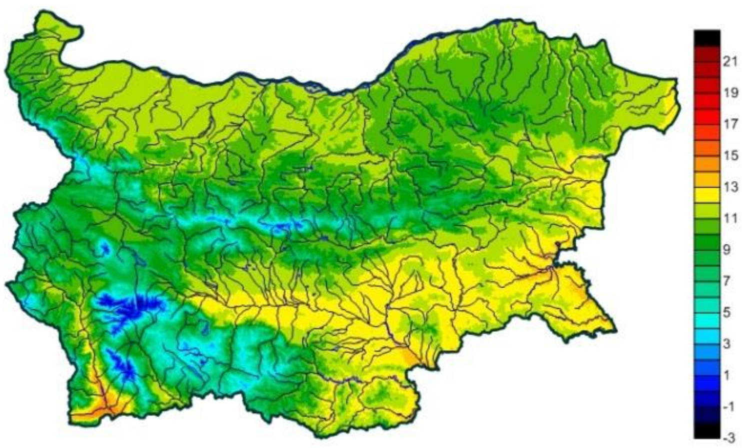
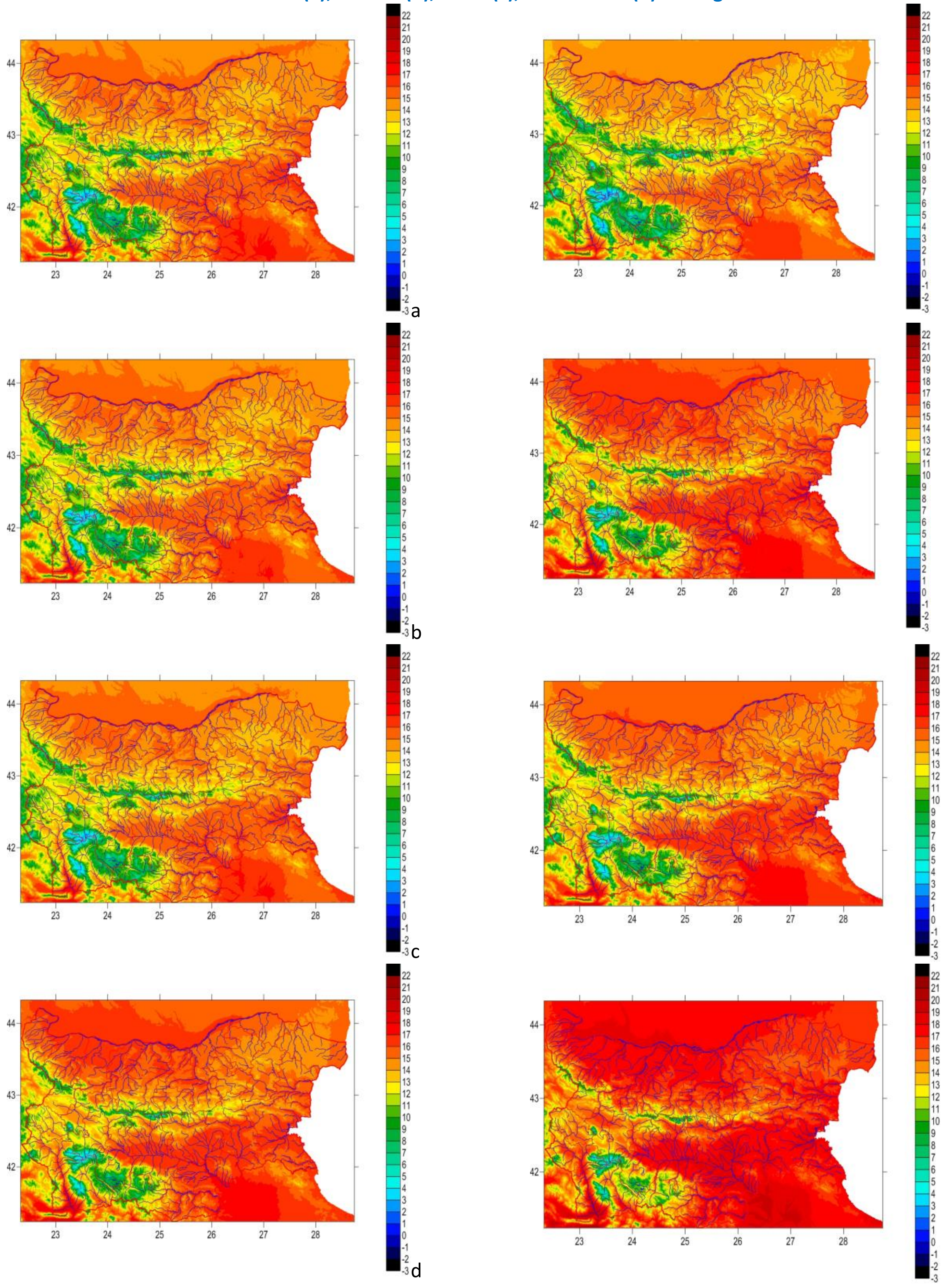


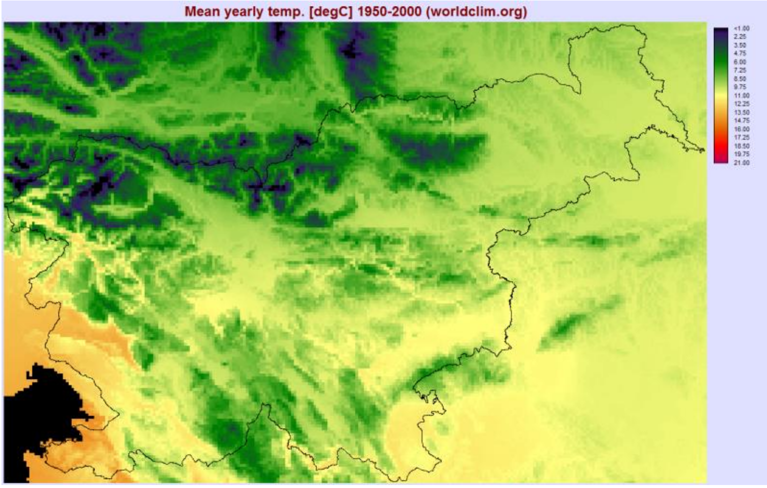
Figure 4.2. Projected changes in annual mean temperature (°C) in 2050 (left) and 2070 (right) at RCP2.6 (a), RCP4.5 (b), RCP6 (c), and RCP8.5 (d) in Bulgaria.



4.1.2. Slovenia

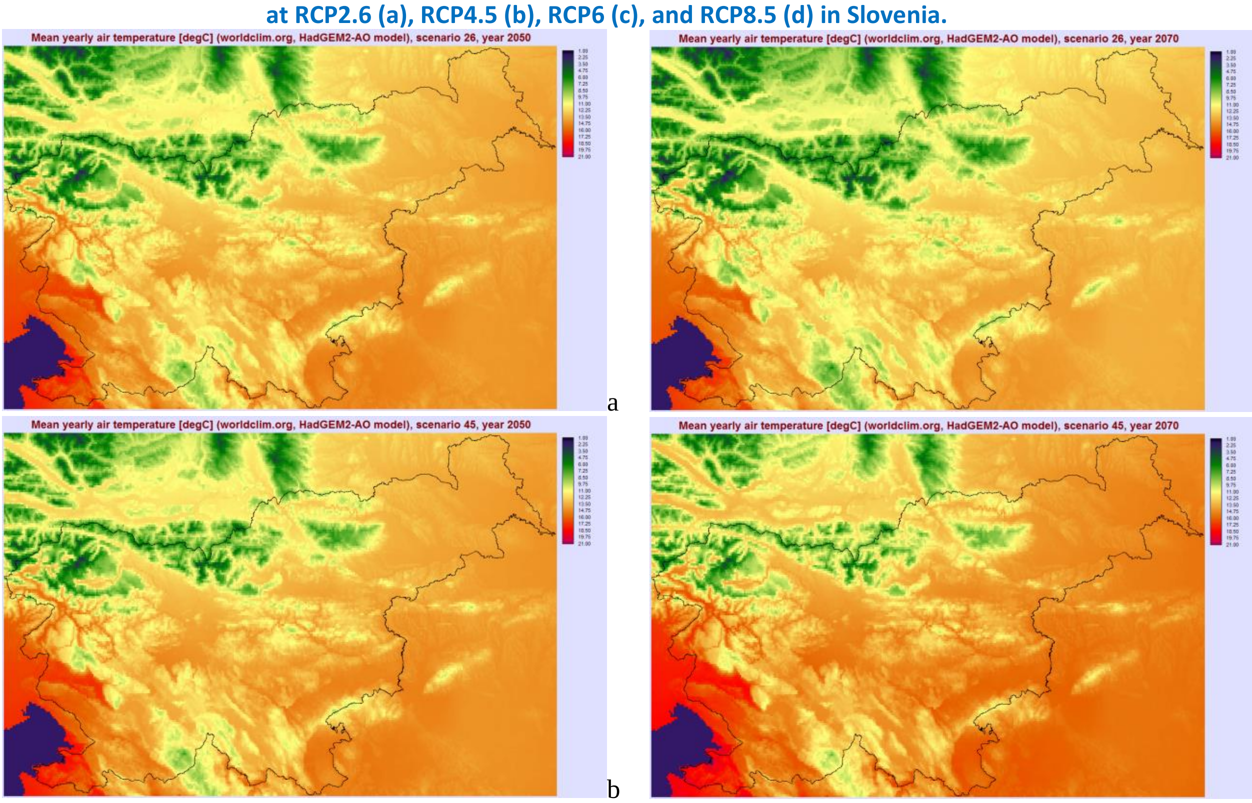
The mean annual air temperature in current climate (1950-2000) in Slovenia is presented in Figure 4.3. Using the WorldClim data, the calculated annual air temperature in period 1950-2000 in Slovenia is between -1.2^{0}C and 14.5^{0}C. In current climate the mean annual air temperature is 8.9^{0}C. The mean annual temperature on the highest mountains in the northern part of Slovenia is less than 2.5^{0}C.

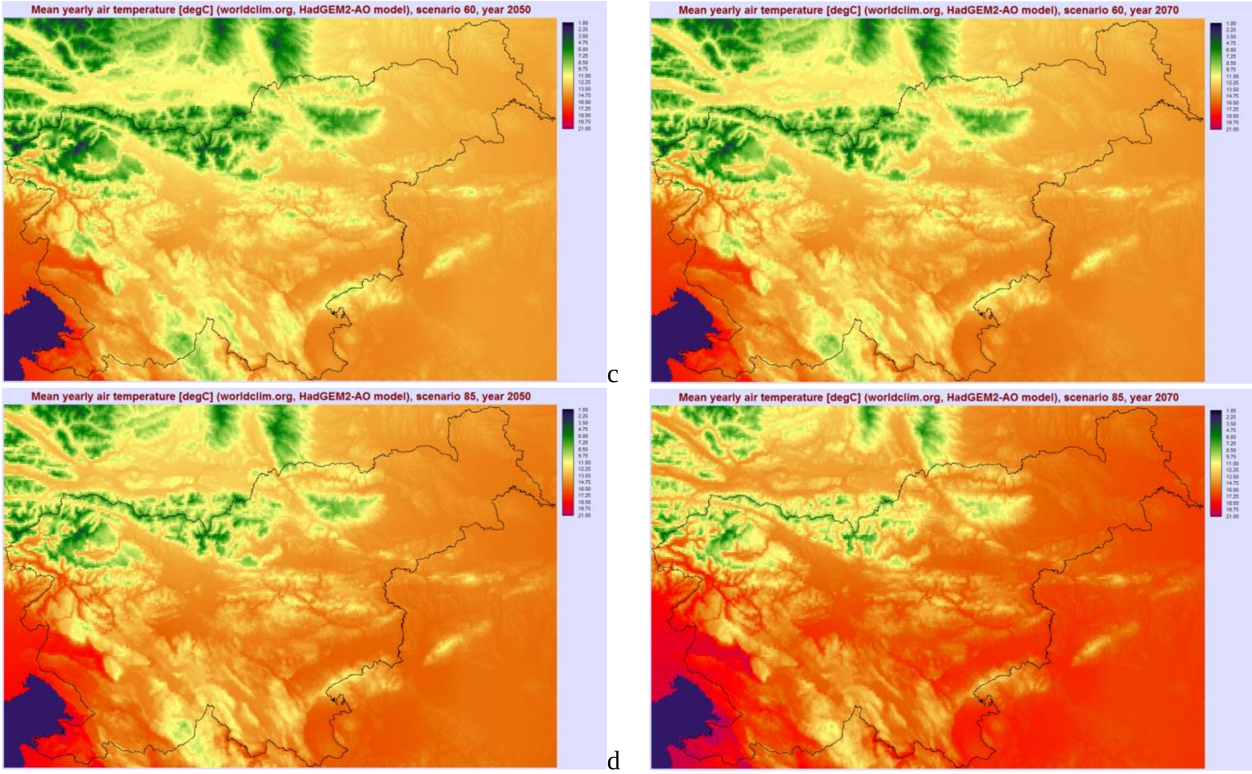
Figure 4.3. Annual mean temperature in current climate (1950-2000) in Slovenia.



IPCC AR5 based air temperature forecast for 2050 and 2070 according to RCPs is shown in Figure 4.4.
At the optimistic scenario RCP2.6 in 2050, the mean annual air temperature is expected to be increased to 12.4^{0}C (Figure 4.4). The annual air temperature will vary between 2.1^{0}C and 18.0^{0}C. However, according to model used the mean annual air temperature in 2070 will be even lower than in 2050. It is predicted to be 11.7^{0}C. The annual air temperature in year 2070 will be between 1.5^{0}C and 17.3^{0}C.
Comparing to the current climate, the increase of the annual air temperature is even more significant at the pessimistic scenario RCP8.5 (Figure 4.4). To the year 2050, the mean annual temperature will rise for almost 5^{0}C. Based on prediction, it will be between 3.5^{0}C and 19.3^{0}C. At the scenario RCP8.5 the annual air temperature in year 2070 will be between 4.9^{0}C and 20.8^{0}C.
Assuming the change of temperature could be between optimistic and pessimistic scenarios, the climate warming to 2050 in Slovenia region is expected to be around 3.5^{0}C at RCP2.6, and around 4.8^{0}C at RCP8.5.
Respectively, the climate warming in the country to 2070 will be for 2.8^{0}C at RCP2.6, and for 6.2^{0}C at RCP8.5.

Figure 4.4. Projected changes in annual mean temperature (°C) in 2050 (left column) and 2070 (right column) at RCP2.6 (a), RCP4.5 (b), RCP6 (c), and RCP8.5 (d) in Slovenia.

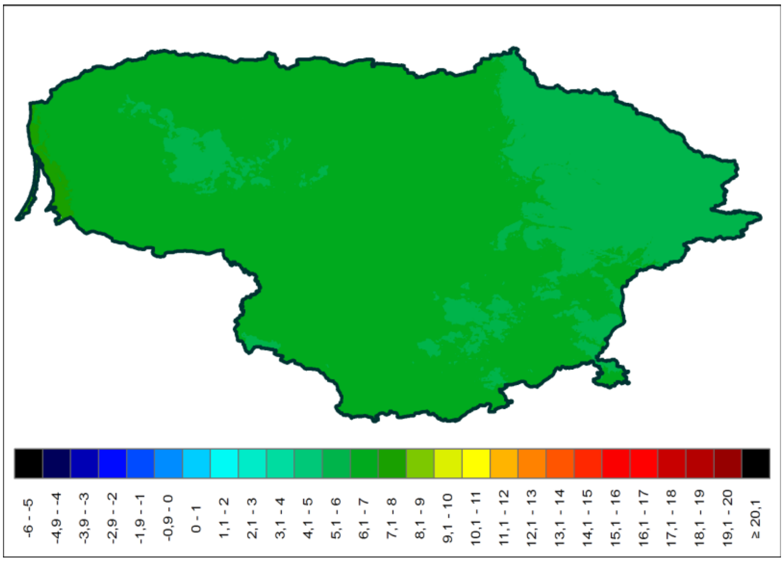




4.1.3. Lithuania

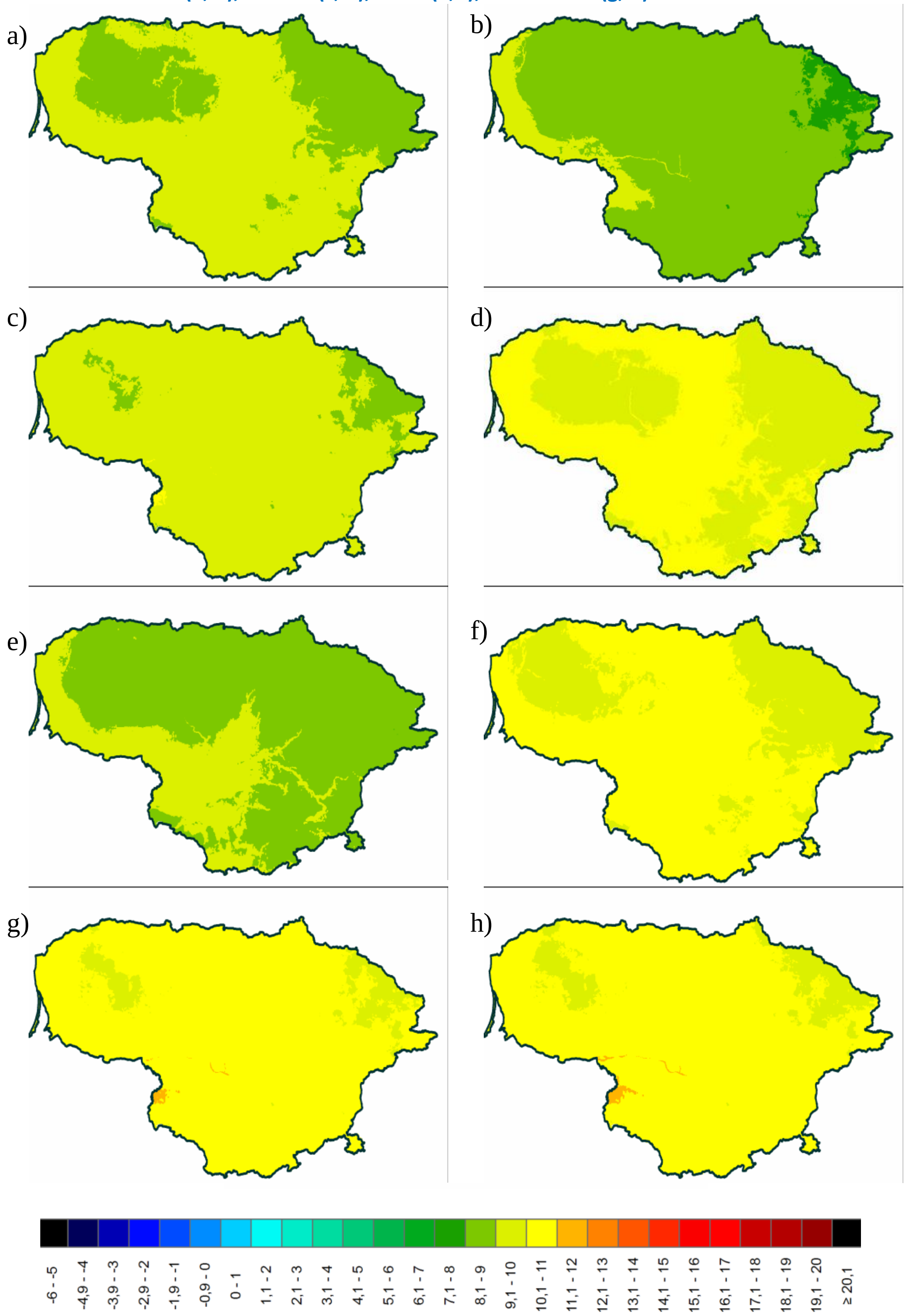
In current climate (1950-2000) the highest average annual temperature 7.3°C found within the Baltic Sea coastline and surrounded areas, while the lowest 5.1°C in the north eastern corner of territory as well as in Zemaiciu Upland. The prevailing range of the average annual air temperature values is between 5.9 and 6.6°C (Figure 4.5).

Figure 4.5. Annual mean temperature in current climate (1950-2000) in Lithuania.



According to HadGEM2-AO outputs the most apparent increase in temperature until 2050 will occur following scenarios RCP4.5 and RCP8.5 – 1.5–3°C (Figure 4.6). The most intensive warming is expected in the southwestern part of Lithuania. However between 2050 and 2070 the temperature will further increase according to all scenarios except RCP2.6.

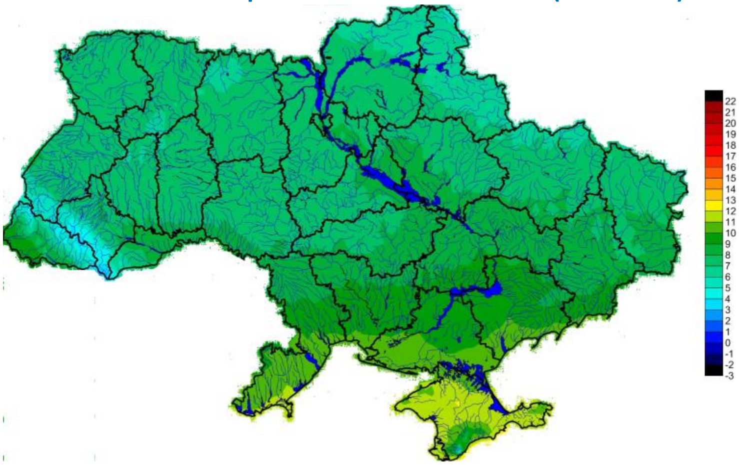
Figure 4.6. Projected changes in annual mean temperature (°C) in 2050 (left) and 2070 (right) at RCP2.6 (a, b), RCP4.5 (c, d), RCP6 (e, f), and RCP8.5 (g, h) in Lithuania.



4.1.4. Ukraine (pilot area)

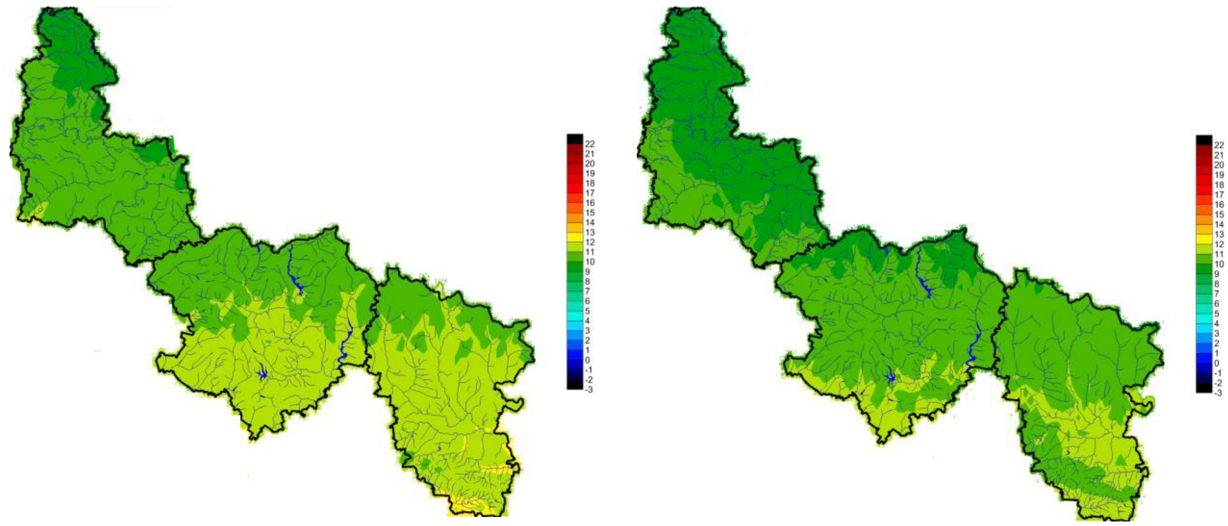
At the pilot area of Ukraine the average annual temperatures range from 5.6°C to 8.8°C in current climate (1950-2000). The highest average annual temperature is on the south-east (in Lugansk region), and the lowest – on the north (in Sumy region) (Figure 4.7).

Figure 4.7. Annual mean temperature in current climate (1950-2000) in Ukraine.

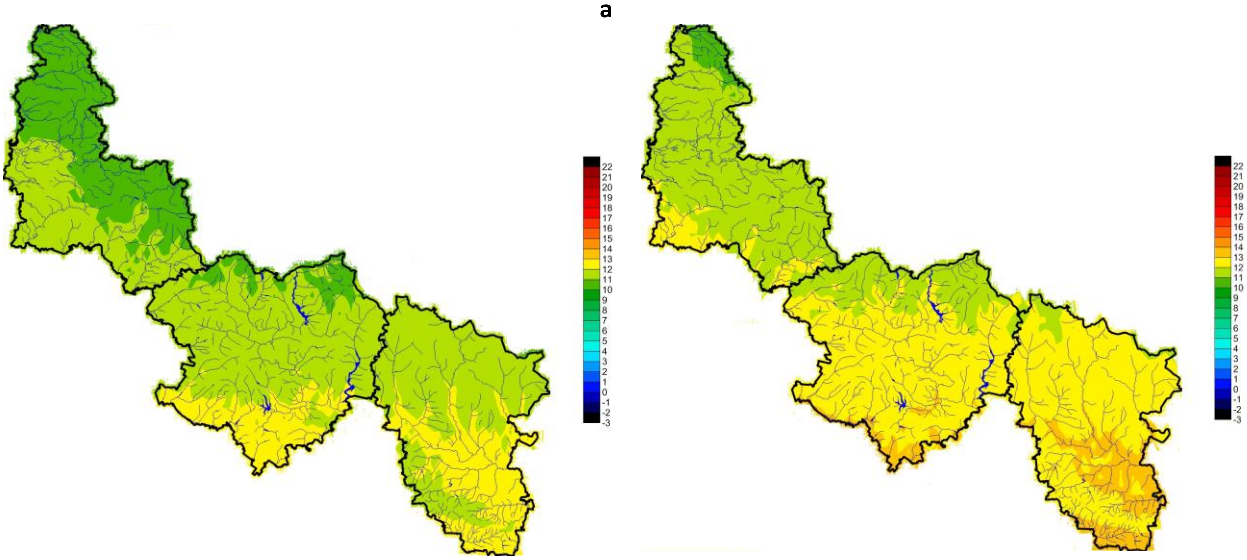


According to all RCP scenarios the significant increase of temperature is expected at the whole pilot area (by 3-4°C) (Figure 4.8). The most intensive warming is expected in the southeast.

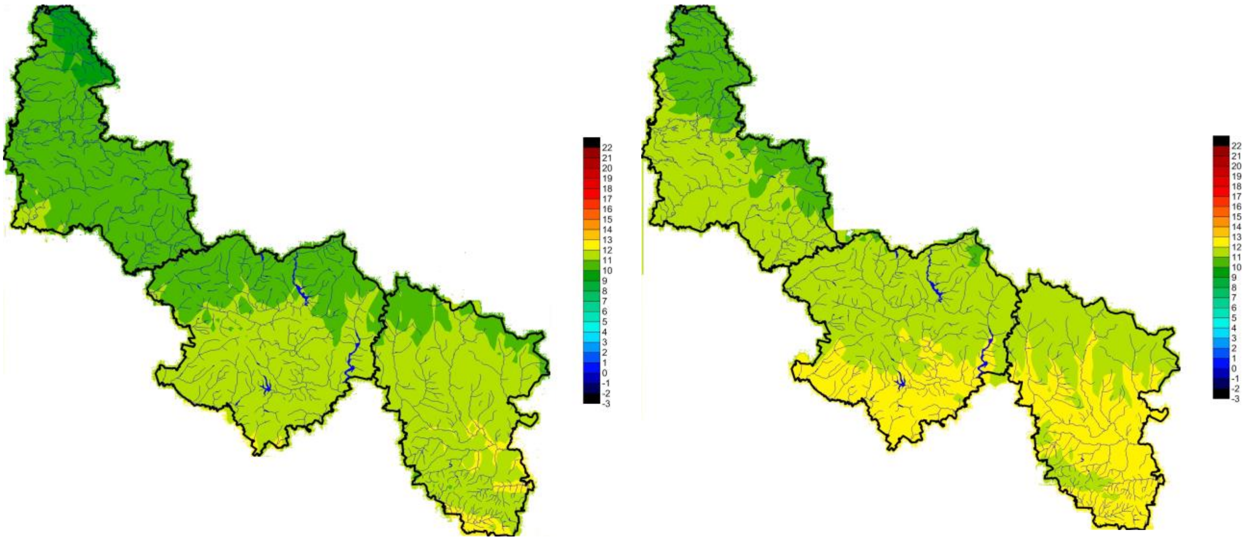
Figure 4.8. Projected changes in annual mean temperature (°C) in 2050 (left) and 2070 (right) at RCP2.6 (a), RCP4.5 (b), RCP6 (c), and RCP8.5 (d) in Ukraine (pilot area).



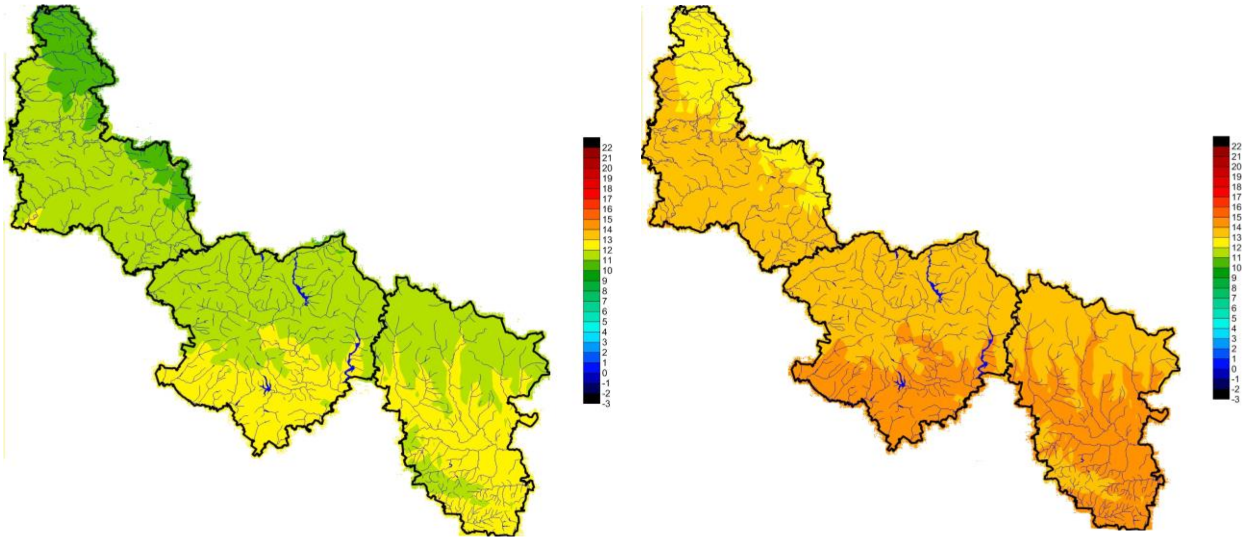
a



b



c



d

The most optimistic scenario RCP2.6 shows temperature increasing by 3.5-3.6°C till 2050 and by 2.9-3.1°C till next two decades. About RCP6.0 forecasts gradual increasing of annual temperature till 2050 (by 3.6-3.8°C) and by 4.2-4.4°C till 2070. Between 2050 and 2070 the temperature will continue to increase according to all scenarios except RCP2.6.

The most pessimistic climatic scenario is RCP8.5 that forecasts increasing of average annual temperature by 4.1-4.5°C till 2050, and further by 2°C comparing to 2050.

In 2050 and 2070 at the optimistic scenario RCP2.6 the significant increasing of the average annual air temperature is expected by 3°C-3.5°C comparing to the current climate.

According to the RCP8.5 the increase of the air temperature is more significant. By 2050, average temperatures will rise by 4°C. Further by 2070 air temperature will rise by 2°C comparing to 2050.

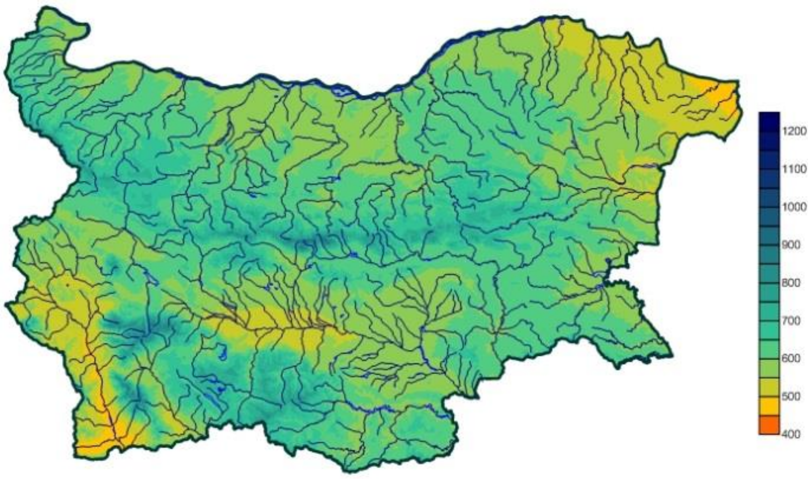
It is expected warming in winter month (winters will become milder), vegetation season will become longer and start one month earlier – in March, and finished one month later – in November. The most significant changes are expected for summer period – the mean month temperature will increase on more then 5°C.

4.2.Precipitation

4.2.1.Bulgaria

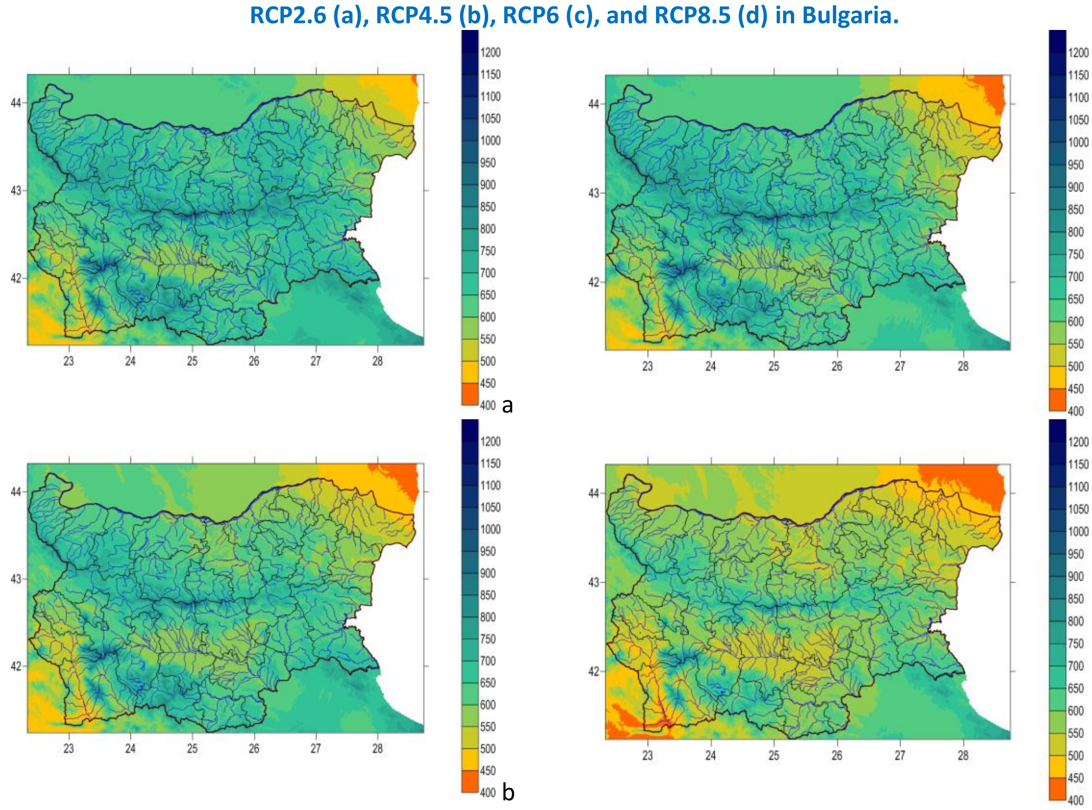
The annual precipitation in current climate (1950-2000) is shown in Figure 4.9. The annual precipitation in lowland areas is between 450-650 mm, but in the mountains reaches 1000 to 1100 mm. This corresponds with the precipitation results of current climate 1961-1990 (Koleva and Peneva. 1990).

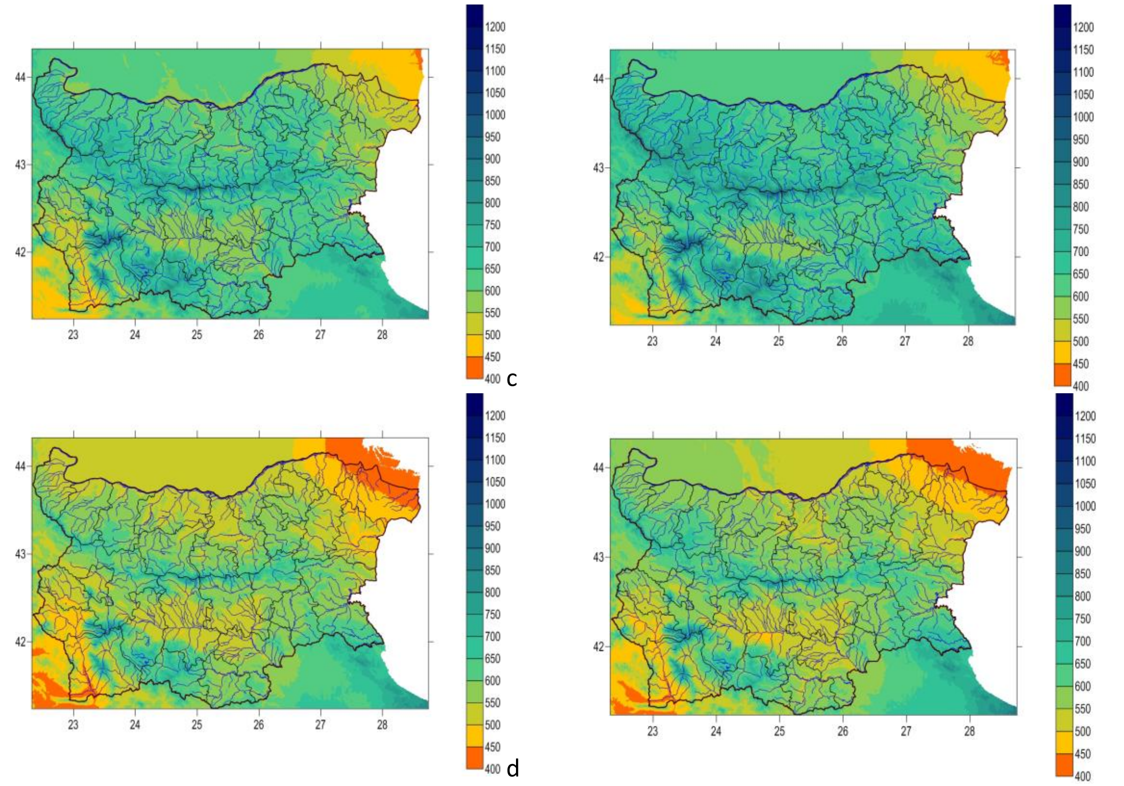
Figure 4.9. Annual precipitation in current climate (1950-2000) in Bulgaria.



Significant changes in precipitation are not expected in RCP2.6. For the years of 2050 and 2070, the expectation is for less rainfall in the Northeast Bulgaria only (Figure 4.10).

Figure 4.10. 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) in Bulgaria.



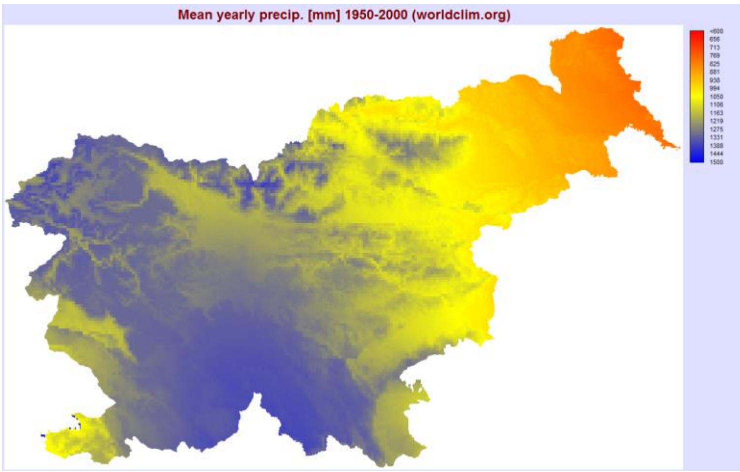


At RCP8.5, a significant reduction of precipitation seems to be in Northeast Bulgaria, Dobrudja, Southwest Bulgaria and Maritsa river basin mainly. Furthermore, the expected change in the annual regime of precipitation is as follows: increase in winter precipitation and reduction of rainfall during the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

4.2.2. Slovenia

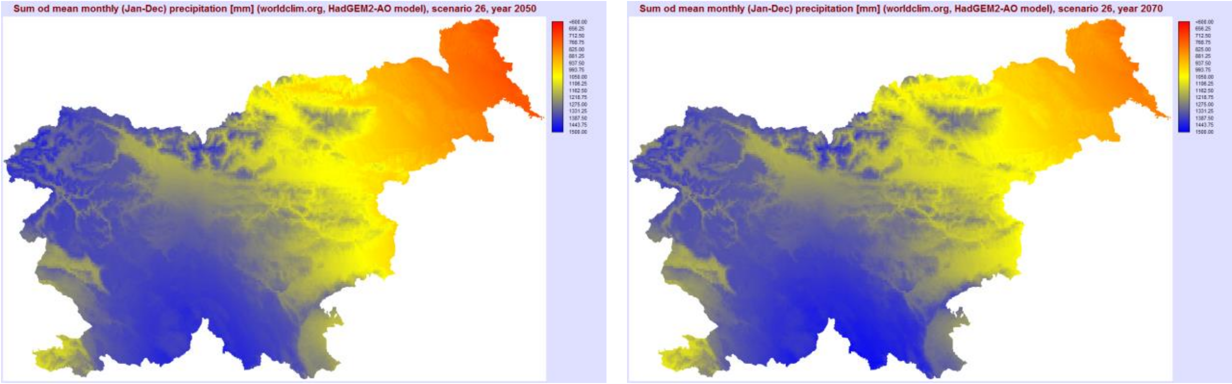
Based on WorldClim data, the calculated annual precipitation in the period 1950-2000 in Slovenia is between 777 mm and 1404 mm. In current climate, the mean annual precipitation is 1182 mm. (Figure 4.11).

Figure 4.11. Annual precipitation in current climate (1950-2000) in Slovenia.

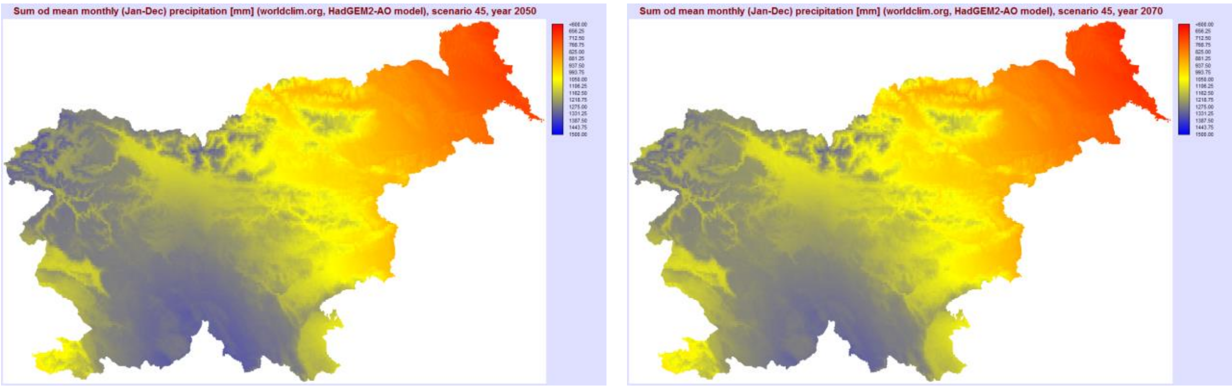


According to HadGEM2-AO outputs based on the RCP2.6 scenario, there will be no significant changes in precipitation amount to year 2050 (Figure 4.12). At the RCP2.6 scenario, the annual precipitation in Slovenia in year 2050 will be between 724 mm and 1443 mm, and mean annual precipitation will be 1187 mm. However, the slight reduction of the precipitation amount might be expected at the pessimistic RCP8.5 scenario. At this scenario in year 2050, the precipitation amount will vary between 654 mm and 1330 mm, and mean annual precipitation will be 1092 mm. In year 2070, the mean annual precipitation will be between 1102 mm and 1223 mm. At the RCP8.5, the most significant reduction of the precipitation amount is expected in the north-eastern part of Slovenia, and in Dinaric mountains and Alps. However, the decrease of precipitation amount and the changes of precipitation regime will affect different types of forest vegetation.

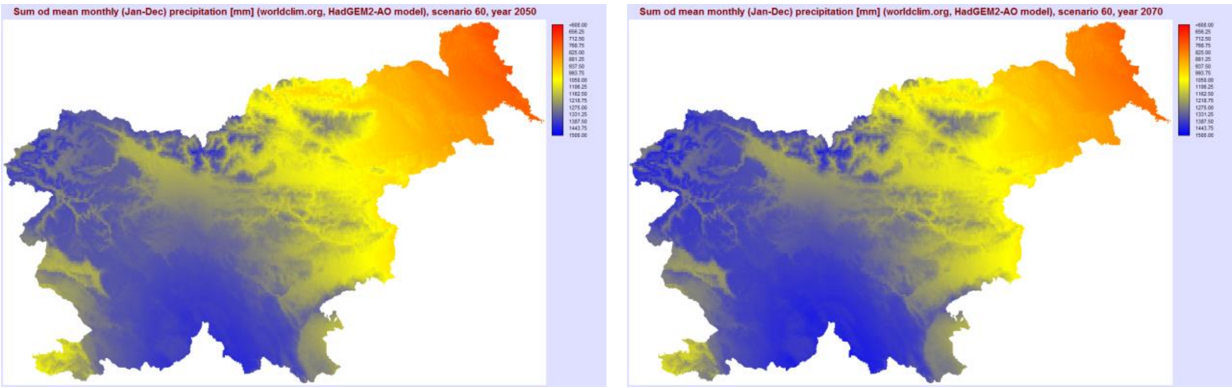
Figure 4.12. Projected chnages in annual precipitation (mm) in 2050 (left column) and 2070 (right column) at RCP2.6 (a), RCP4.5 (b), RCP6 (c), and RCP8.5 (d) in Slovenia.



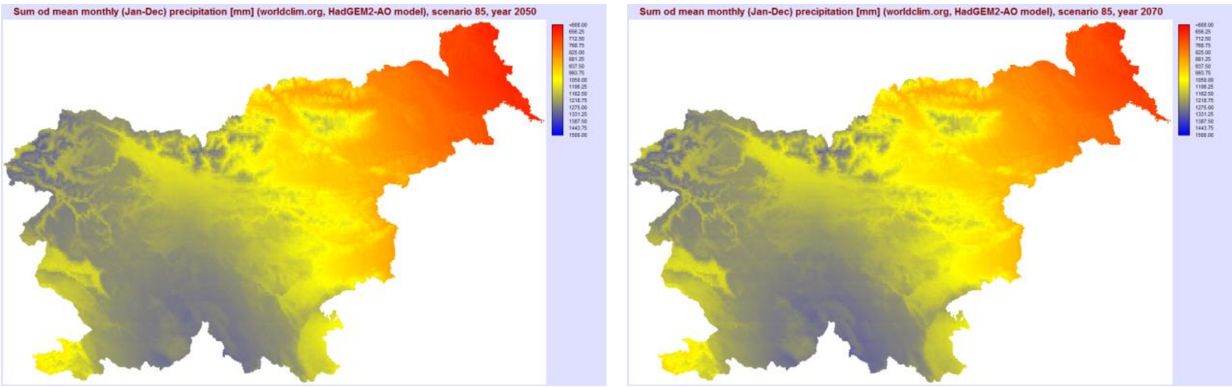
a



b



c

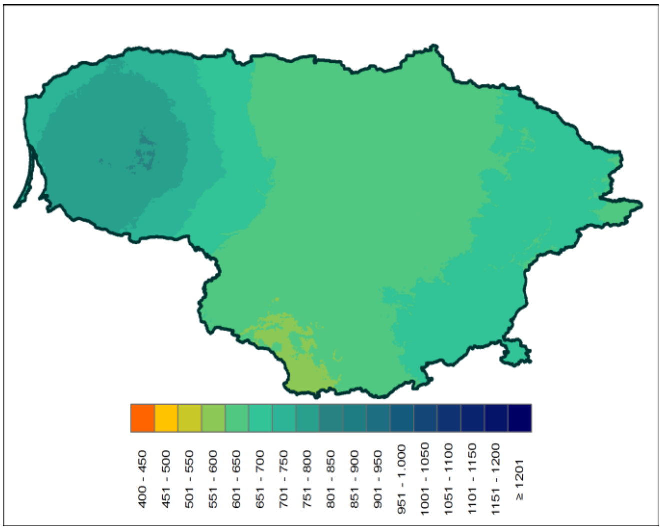


d

4.2.3.Lithuania

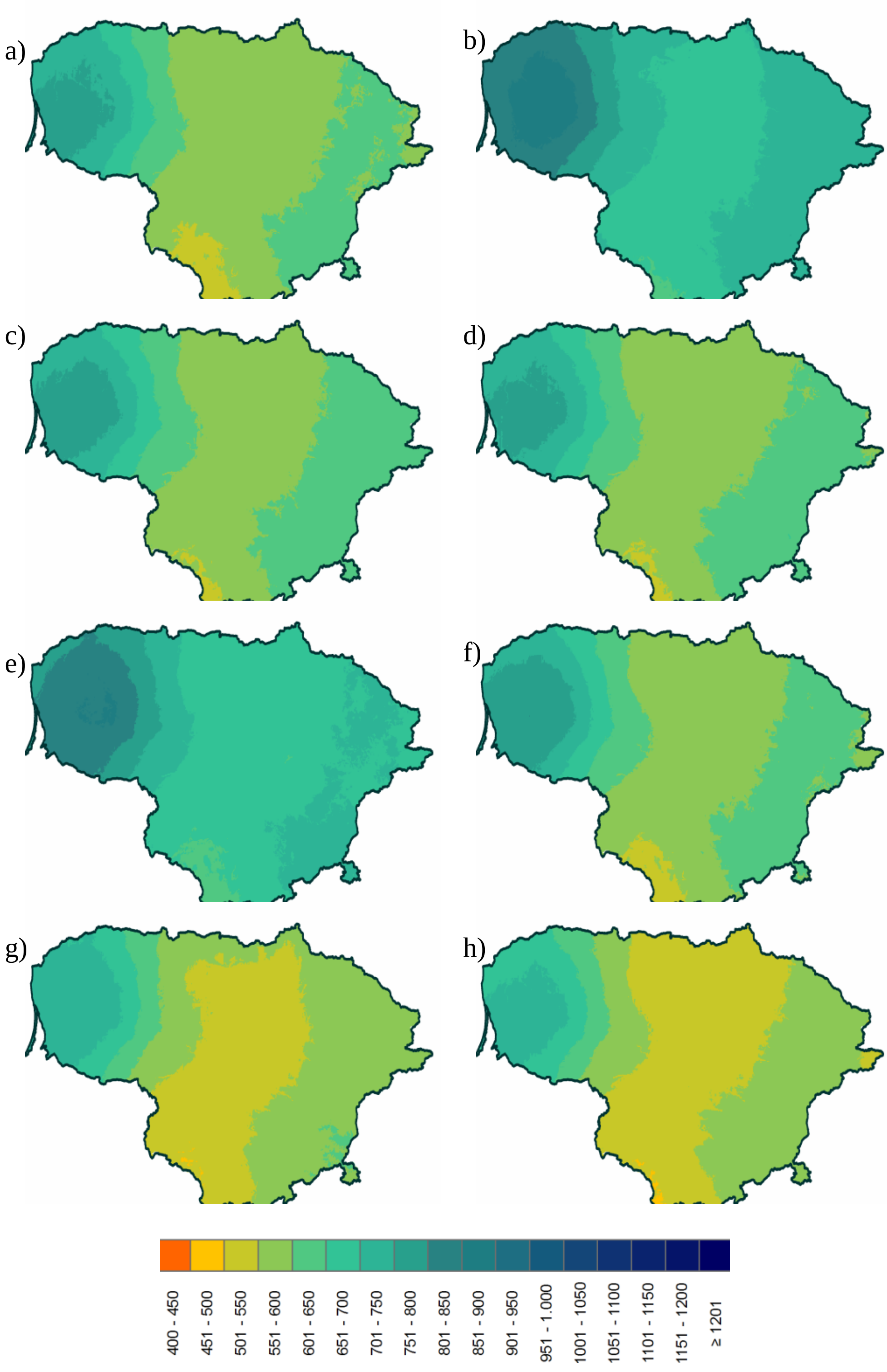
In current climate (1950-2000) the drier areas situated within central and northern part of territory, and the south-western corner gets least amount of precipitation (497 mm). Precipitation amount increases to the east and to the west from the Middle Lithuania Lowland: in the eastern side it varies from 570 to 650 mm and more than 650 mm – in Zemaiciu upland with maximum amount (750 mm) in the windward slopes of this upland (Figure 4.13).

Figure 4.13. Annual precipitation in current climate (1950-2000) in Lithuania.



Annual precipitation will decrease almost in all territory except western part of Lithuania where cold season precipitation (mainly autumn and winter) will increase the annual precipitation amount (Figure 4.14). The significant decrease in annual precipitation will occur in the central part of Lithuania according to scenario RCP8.5 – approximately 100-150 mm. The main reason is that the summer precipitation decrease. This region however is the main agricultural area with predominant arable land in Lithuania.

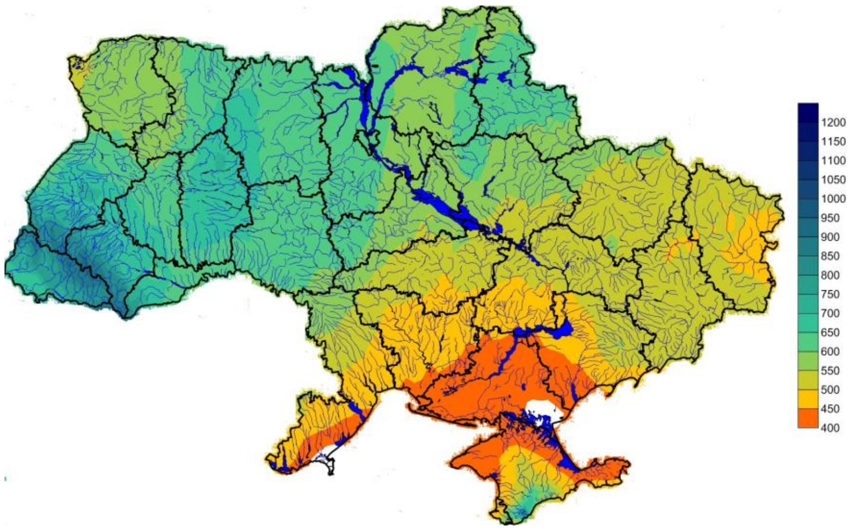
Figure 4.14. Projected changes in annual precipitations (mm) in 2050 (left) and 2070 (right) at RCP2.6 (a, b), RCP4.5 (c, d), RCP6 (e, f), and RCP8.5 (g, h) in Lithuania.



4.2.4. Ukraine (pilot area)

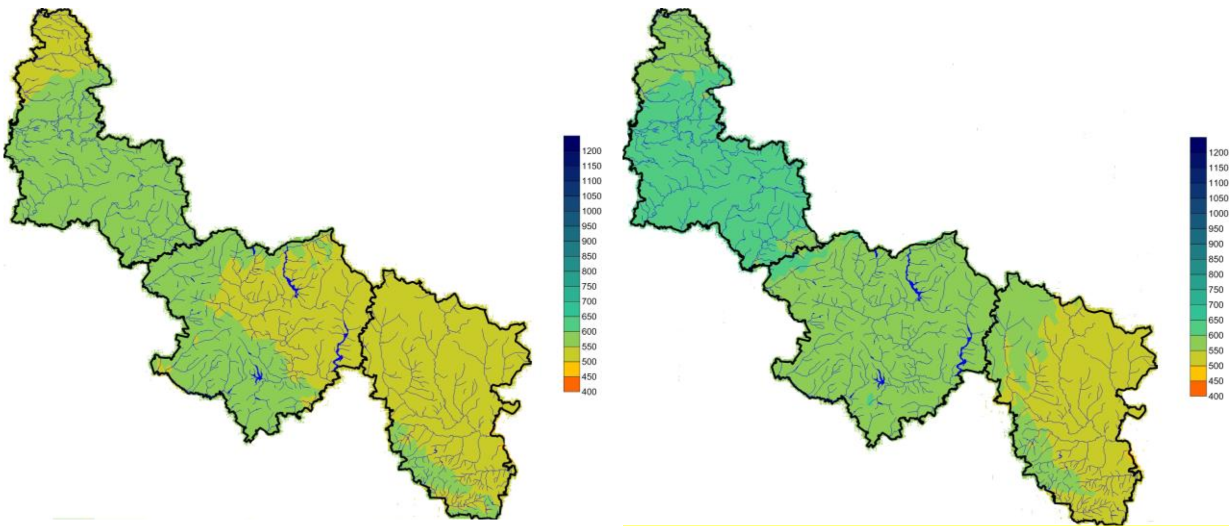
In current climate (1950-2000) the pilot area of Ukraine receives annual precipitation in range from 641 mm on the north to 474 mm on the south-east (Figure 4.15).

Figure 4.15. Annual precipitation in current climate (1950-2000) in Ukraine.

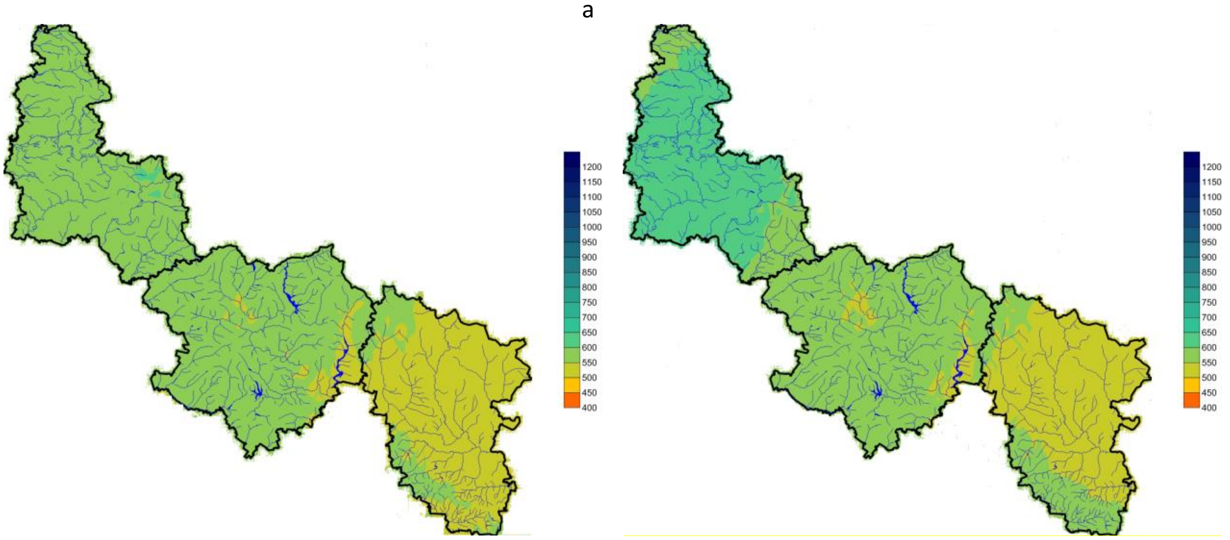


According to RCP2.6 and RCP4.5 there will be no significant changes in annual precipitation at the main part of pilot area till 2070 (Figure 4.16).

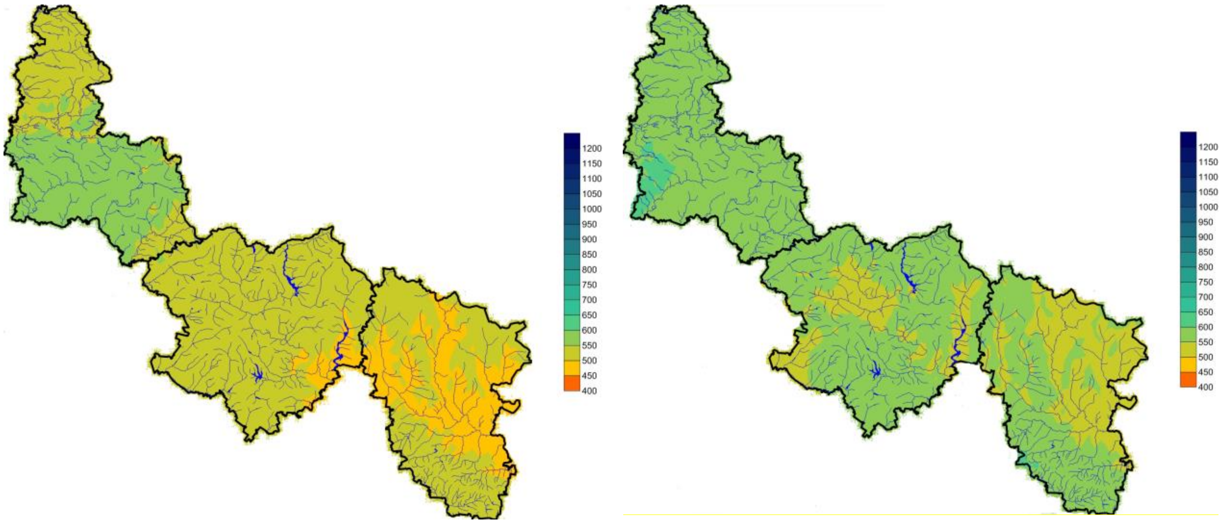
Figure 4.16. Projected changes in annual precipitation (mm) in 2050 (left) and 2070 (right) at RCP2.6 (a), RCP4.5 (b), RCP6 (c), and RCP8.5 (d) in Ukraine (pilot area).



a



b



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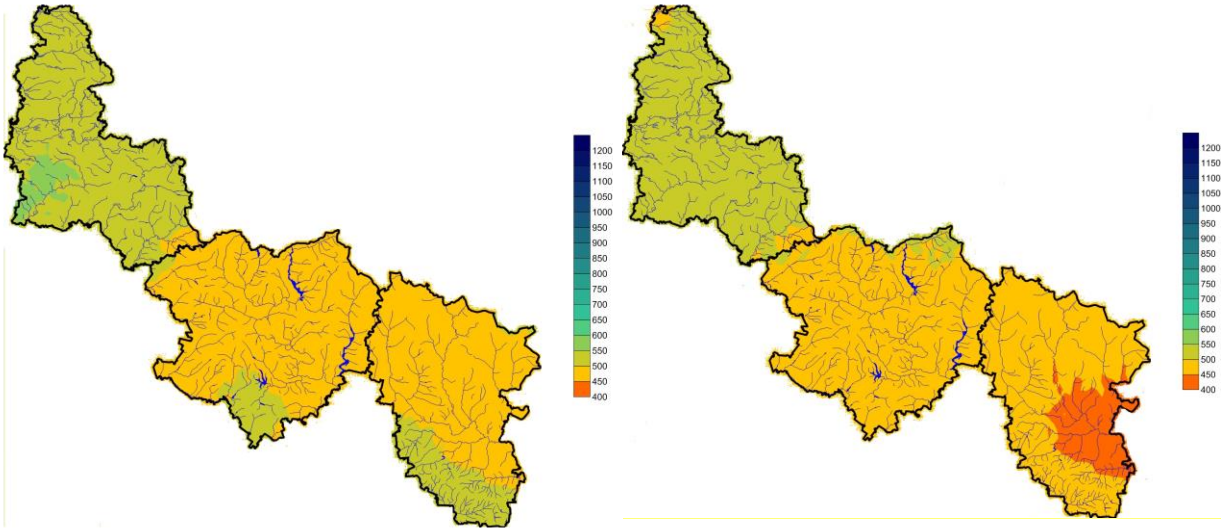


d

Scenario RCP 8.5 forecasts significant decreasing of precipitation on whole territory (by 2070-th by 54-82 mm or 11-13%) (Figure 4.16):

- in 2050 the annual precipitation will be lower then 500 mm at Kharkiv and Lugansk regions, and between 500-550 at the northern part (Sumi region),
- till 2070 in eastern part of Lugansk region annual precipitatioin will be lower then 450 mm.

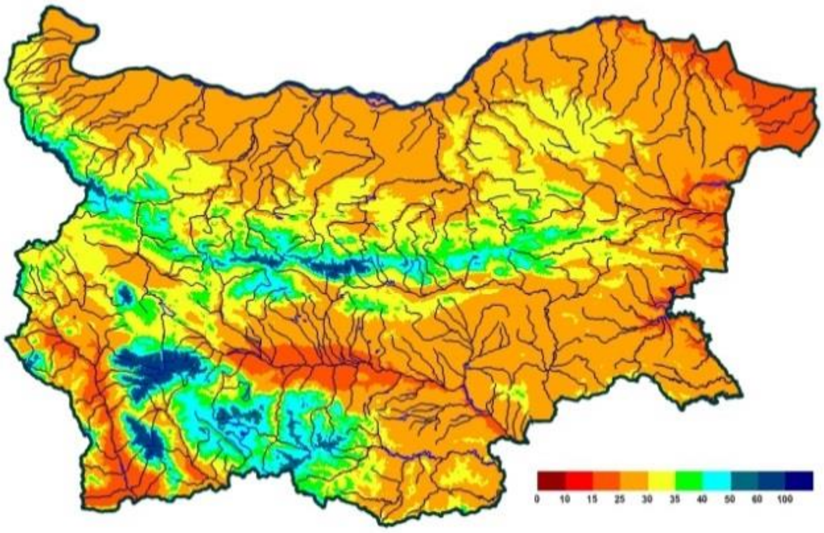
Studied scenarios provide redistribution of precipitation within the year: in current climate maximum precipitation is in summer. Decreasing of precipitation in summer and their increasing in winter is expected under IPCC RCPs. RCP2.6 mostly forecasts decreasing of precipitation in summer and increasing in autumn, RCP4.5 scenario models decreasing of precipitation in summer and increasing in spring and in autumn. According to RCP8.5 the significant decreasing of precipitation during vegetation season is expected.

4.3. De Martonne index and vulnerability zones

4.3.1. Bulgaria

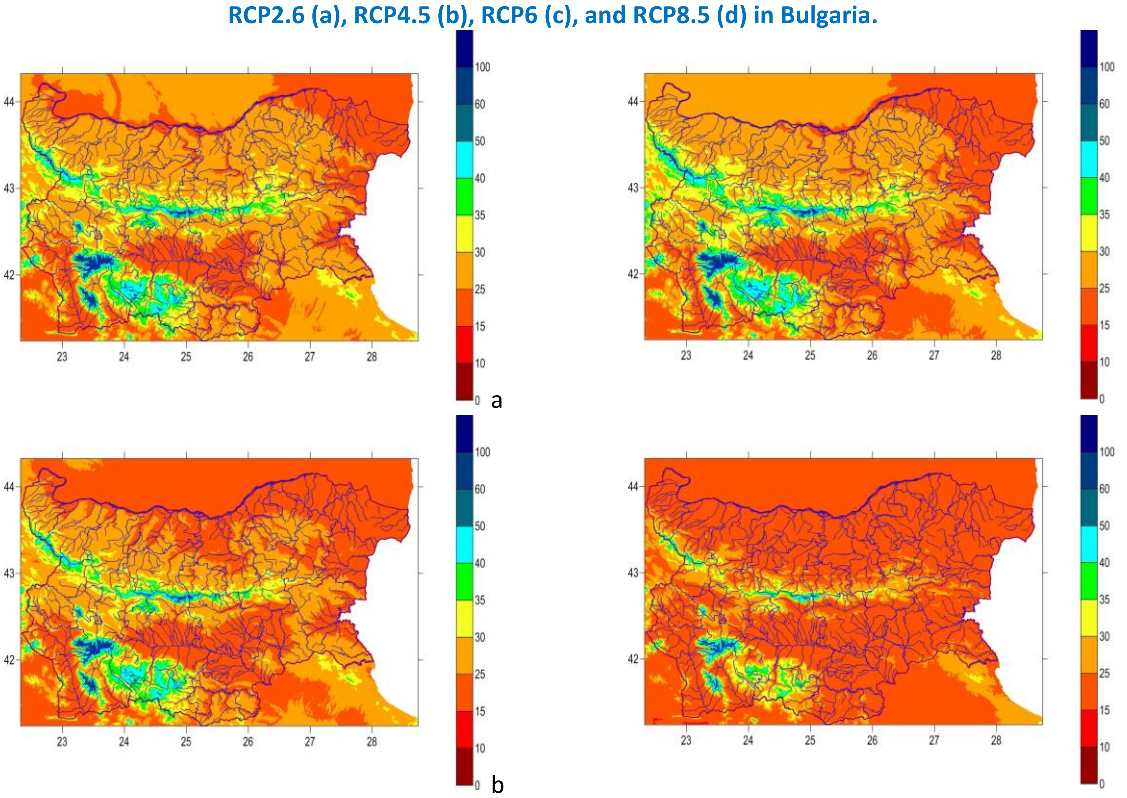
The vulnerability zone A (IDM 10-25) in current climate (1950-2000) occupies small areas in Northeast Bulgaria, the valleys of the rivers Struma and Maritsa and some Black sea rivers (Figure 4.17). Zone B (IDM 25-30) covers the largest areas in the plains and hilly part to 500-600 m a.s.l. with lasting disturbances of the moisture. Zone C (IDM 30-35) covers the foothills of the Balkan Mountains, Ludogorie and high plains. Here the conditions are more favorable. In zone D (IDM 35-40) the forests have medium vulnerability level with small disturbances of the moisture in some years. Zone D covers the large areas in the Balkan Mountains and other mountains areas of 700-1000 m a.s.l. Zone D has good conditions for development of forests. The forests in zone E (IDM 40-50) have low vulnerability level with optimal moisture conditions. Zone E covers areas from 1000 to 1400 m a.s.l. Zone F (IDM 50-60) - low vulnerability level in the belt from 1400 to 1700 m a.s.l. Zone F is with optimal environmental conditions for the forest. Zone G (IDM 60-187) is in the high mountains from 1700 to 2925 m a.s.l.

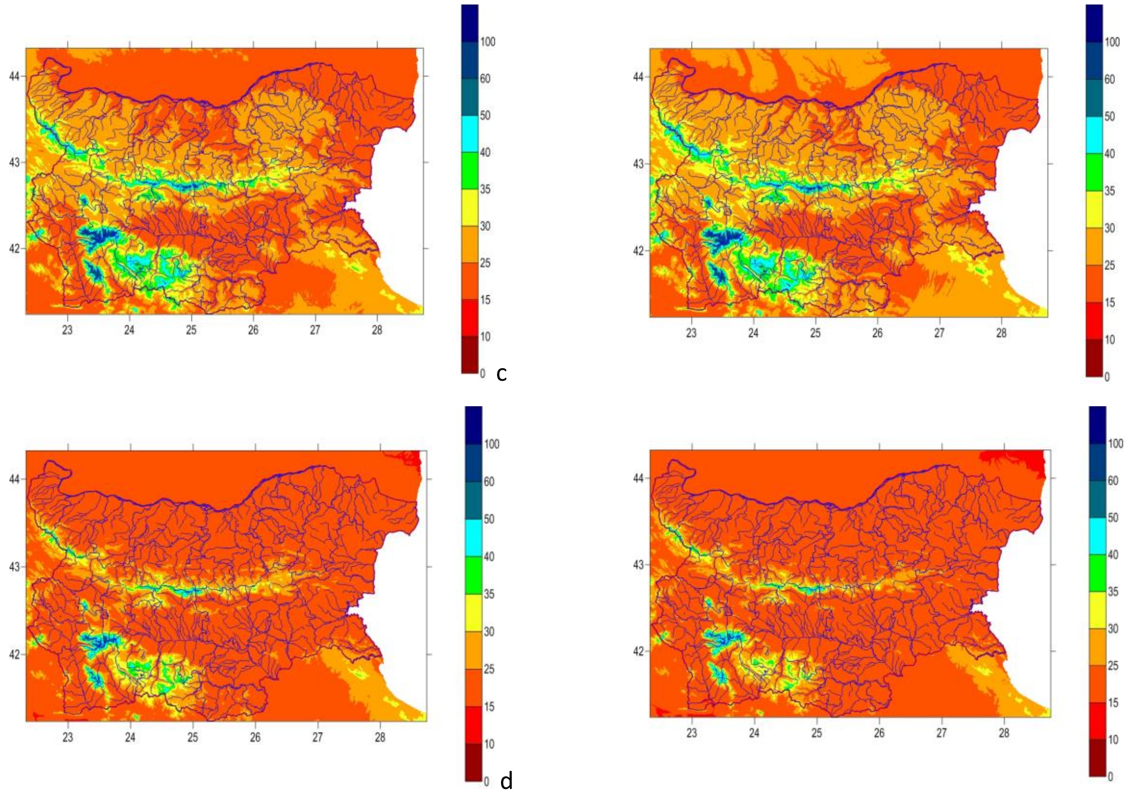
Figure 4.17. De Martonne aridity index in current climate (1950-2000) in Bulgaria.



At the RCP2.6, the zone A is growing mainly in: Northeast Bulgaria, the valleys of the rivers Struma and Maritsa, and the Thracian valley (Figure 4.18). Zone B covers large areas in North and South Bulgaria and high fields. The forest areas in other zones C, D, E, F, G will reduce. At the RCP4.5, the zone A is increasing strongly, especially in 2070, covering most of the country. All other zones are decreasing. The optimal conditions for forests are limited. RCP6.0 shows some improvement of the environmental conditions. The most unfavorable zoning is at RCP8.5 , which will lead to severe environmental conditions for the forests.

Figure 4.18. 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) in Bulgaria.

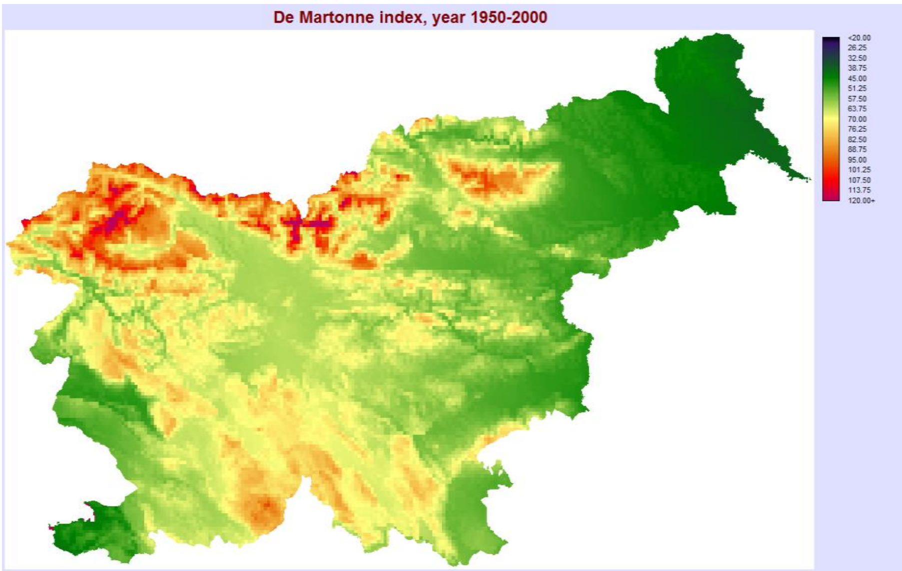




4.3.2. Slovenia

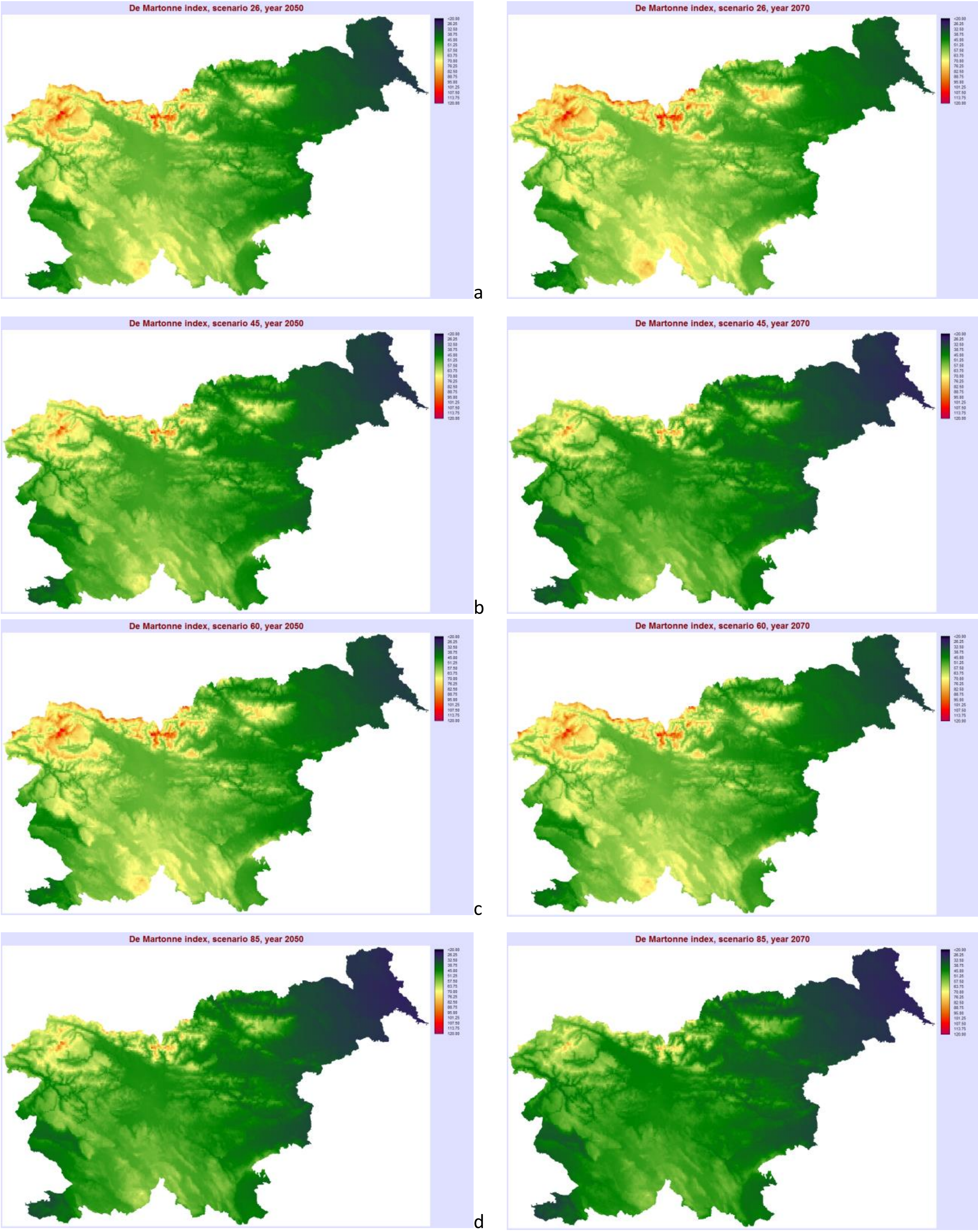
In current climate, the values of De Martonne index vary from around 30 and to more than 110. The lowest values were calculated for eastern and north-eastern part of Slovenia (Pre-Pannonian region) and for western to south-western part of Slovenia (Sub-Mediterranean region). The highest values (most humid) may be observed in Alpine region in north and in the highest zone of Dinaric region (Figure 4.19).

Figure 4.19. De Martonne aridity index in current climate (1950-2000) in Slovenia.



At all RCP scenarios, the mean values of De Martonne will decrease to year 2050 and 2070. More humid conditions may be expected only in some high elevated parts of Alps in northern part of Slovenia (Figure 4.20).

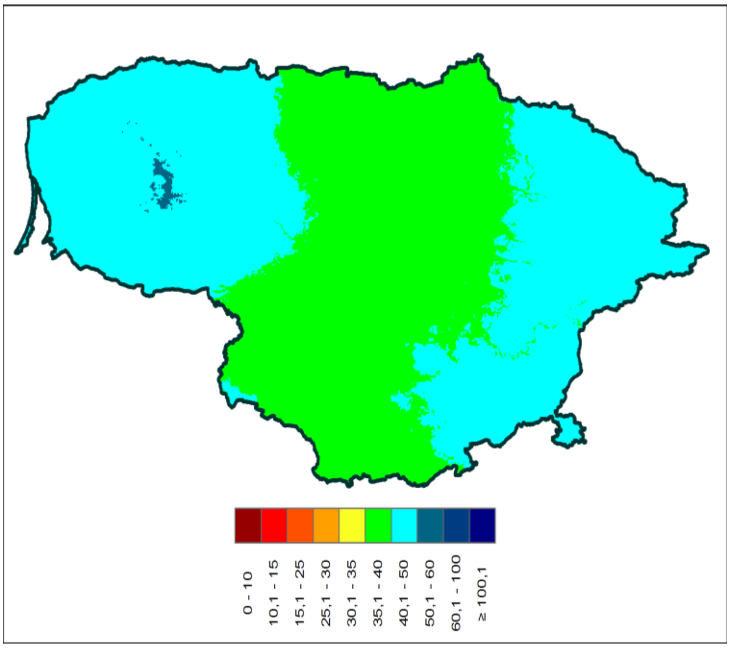
Figure 4.20. Projected changes of De Martonne aridity index in 2050 (left column) and 2070 (right column) at RCP2.6 (a), RCP4.5 (b), RCP6 (c), and RCP8.5 (d) in Slovenia.



4.3.3.Lithuania

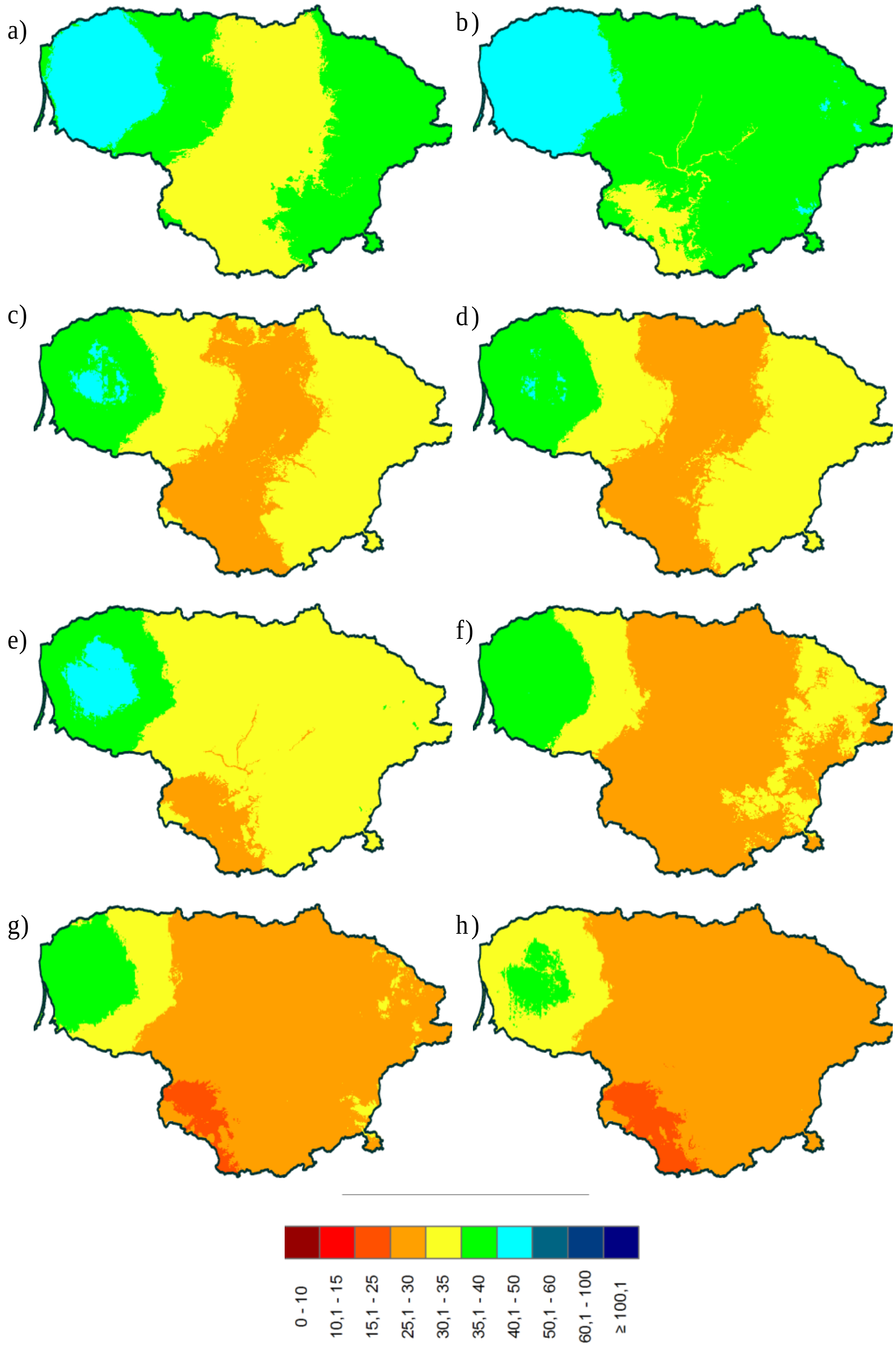
De Marton aridity index values vary from 34.7 in the most south western part of Lithuania to 51 in Zemaiciu upland area (Figure 4.21). The prevailed index values spread between 38 and 44 and therefore correspond to the low and medium vulnerability zones.

Figure 4.21. De Martonne aridity index in current climate (1950-2000) in Lithuania.



The determined De Marton aridity index values for 2050 and 2070 show no areas with high vulnerability level according to scenario RCP2.6. However there are vast area of high vulnerability level according to other scenarios, except RCP6.0 for 2050. Very high vulnerability level areas were detected in the southwestern part of Lithuania according to scenario RCP8.5, while western part depends to medium vulnerability level even in 2070 (Figure 4.22).

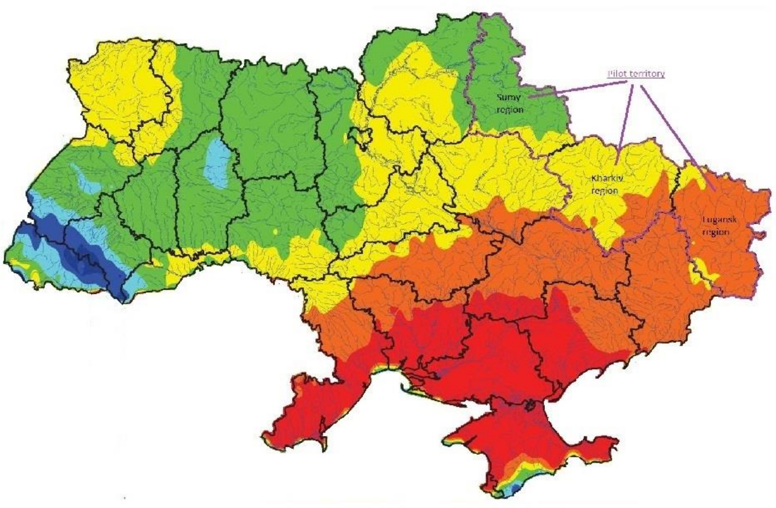
Figure 4.22. Projected changes of De Martonne aridity index in 2050 (left) and 2070 (right) at RCP2.6 (a, b), RCP4.5 (c, d), RCP6 (e, f), and RCP8.5 (g, h) in Lithuania.



4.3.4. Ukraine

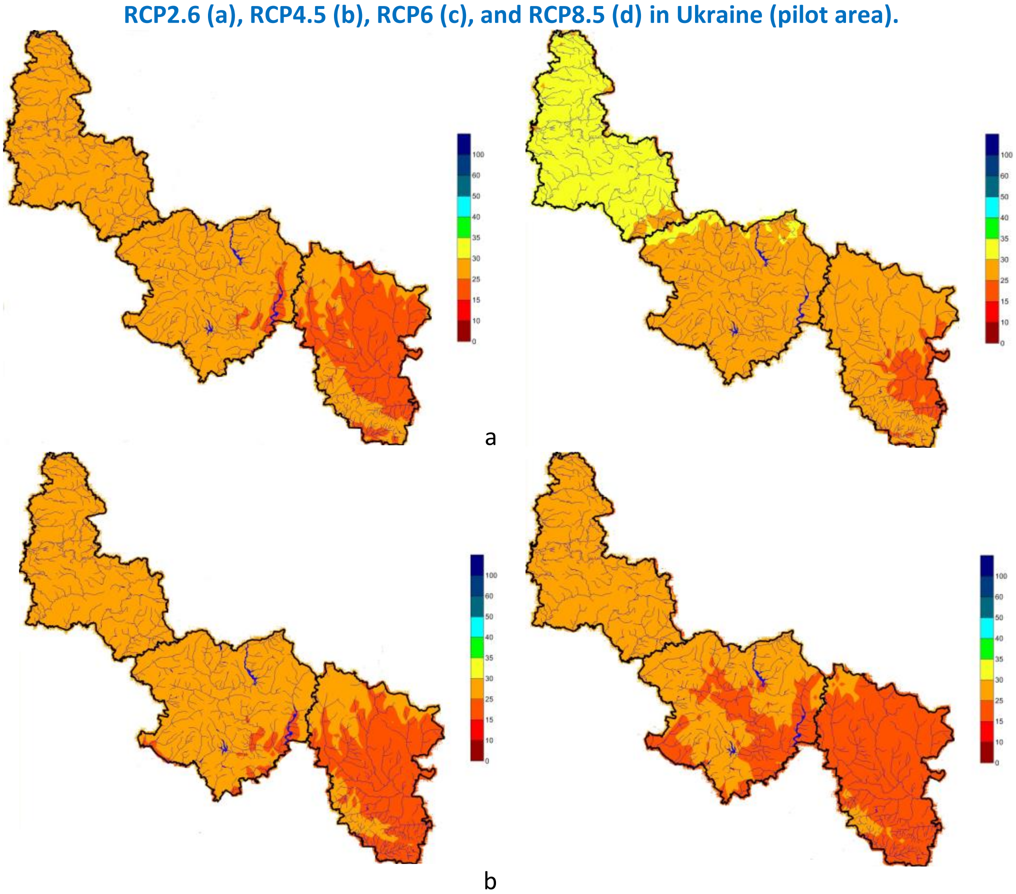
Current climate (1950-2000) of the pilot territory varies from moderately arid on the south to moderately humid on the north (IDM values are in range from 25.6 to 40), that is corresponded to vulnerability zones B, C and D (high and medium vulnerability level) (Figure 4.23). B zone of moderately arid climate (high vulnerability level) is located on the south-east of the pilot area – southern part of Kharkiv region, and almost all territory of Lugansk region (except northern part). C zone of slightly humid climate is located in central part of the pilot territory – at the major part of Kharkiv region and southern districts of Sumy region and at northern part of Lugansk region. D zone of moderate humid climate in present is located at the northern part of pilot area on the major part of Sumy region (except southern part). C and D zones are characterized by medium vulnerability level for forest growth.

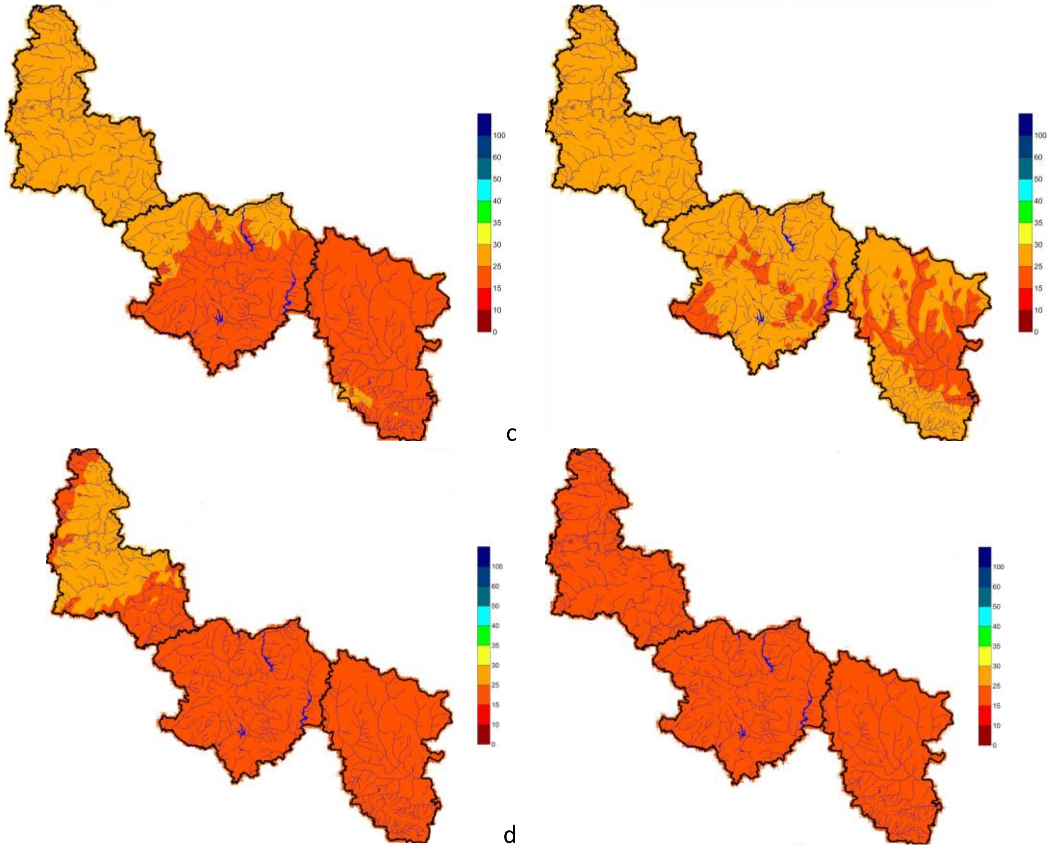
Figure 4.23. De Martonne aridity index in current climate (1950-2000) in Ukraine
(*border of pilot area is marked by purple color*)**.**



All climatic scenarios forecast significant warming and aridization of climate on the whole pilot area till 2050 and 2070 years that is unfavorable for forest vegetation (Figure 4.24).

Figure 4.24. 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) in Ukraine (pilot area).





More severe changes are expected at northern part of the pilot area (Polissya and northern forest-steppe) that will cause disappearance of moderately humid climate (D zone), with the most productive forests. At the same time in all RCP's the new climate – semiarid (A zone of very high level of vulnerability) will appear in varying degrees. In Ukraine in current climate semiarid climatic conditions are observed only outside the pilot area at southern regions of the country.

RCP2.6 is the most soft scenario that is characterized by aridization of climate on the pilot area till 2050, more significant on the north (in Sumy region) where climate will change from moderately humid to moderately arid, less in Kharkiv (change from slightly humid to moderately arid) and appearence of semiarid climate on the south of Lugansk region. By 2070 this scenario provides slight more humid climate comparing to 2050 but not to the current climate values:

- in Sumy region – slight humid climate is expected;
- in Kharkiv and Lugansk – moderately arid;
- semiarid climate will remain only at the south of Lugansk region.

The worst climatic conditions for forest vegetation are expected according to RCP8.5 scenario: by 2050 the large territory (all Lugansk, all Kharkiv regions, southern districts and northern districts of Sumy region) will become semiarid, and by 2070 the whole pilot area will have semiarid climate.

4.4. Forest areas over vulnerability zones

4.4.1. Bulgaria

In current climate (1950-2000) most of the forest areas are in vulnerability zones B (31.5%) and C (31.3%) (Table 4.1).

At the optimistic scenario RCP2.6, most of them are 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 is almost the same - between 31.1% and 41,7%.

At the pessimistic scenario RCP8.5, the biggest part of 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 4.1).

Table 4.1. Total forest areas over vulnerability zones in 2000, 2050 and 2070, Bulgaria.

	A		B		C		D		E		F		G	
Year, RCP	thous.ha	%	thous.ha	%	thous.ha	%	thous.ha	%	thous.ha	%	thous.ha	%	thous.ha	%
2000	186.6	4.5	1319.3	31.5	1307.4	31.3	767.8	18.4	478.1	11.4	109.5	2.6	13.3	0.3
2050 RCP 2.6	642.8	15.4	1707.6	40.8	1069.6	25.6	510.1	12.2	229.2	5.5	20.2	0.5	2.5	0.1
2070 RCP 2.6	685.0	16.4	1561.8	37.3	1052.3	25.2	560.9	13.4	290.8	7.0	28.6	0.7	2.7	0.1
2050 RCP 4.5	966.7	23.1	1703.6	40.7	879.8	21.0	440.0	10.5	174.8	4.2	15.1	0.4	2.0	0.0
2070 RCP 4.5	2200.8	52.6	1300.6	31.1	511.8	12.2	142.5	3.4	22.9	0.5	3.1	0.1	0.4	0.0
2050 RCP 6.0	1051.9	25.2	1694.1	40.5	851.9	20.4	414.7	9.9	156.1	3.7	11.6	0.3	1.7	0.0
2070 RCP 6.0	845.8	20.2	1743.2	41.7	943.8	22.6	456.5	10.9	176.8	4.2	13.8	0.3	2.1	0.0
2050 RCP 8.5	2376.2	56.8	1172.5	28.0	462.6	11.1	143.5	3.4	24.3	0.6	2.7	0.1	0.3	0.0
2070 RCP 8.5	2744.7	65.6	1001.1	23.9	356.8	8.5	68.3	1.6	9.5	0.2	1.6	0.0	0.1	0.0

4.4.2. Slovenia

In current period 1950-2000, in total 73.1% of all forests occur in zone G (Excessively humid), 19.4% in zone F (very humid), 7.4% in the zone E (humid) and 0.1% in the zone D (moderately humid) (Table 4.2).

At the RCP2.6 scenario, only 37.4% of all Slovenian forest is likely to be in zone G in the year 2050. It has been forecasted 38.5% in zone F, 17.6% in zone E, 4.0% in zone D, and 2.4% in zone C.

At the RCP4.5, percentage of forests in zone G will be reduced to 19.5% in 2050 and to 10.4% in year 2070. In both periods, major part of the forests is expected to be in zone F (44.3% in year 2050; and 39.2% in year 2070) and zone E (27.4% in year 2050; and 37.1% in year 2070). At RCP4.5 scenario, significant expansion of moderately arid area (zone B), slightly humid area (zone C) and moderately humid area (zone D) is forecasted in the north-western part of Slovenia (Table 4.2).

At the RCP8.5, only 9.1% of all forests in Slovenia in year 2050 and 3.3% in year 2070 might be classified in zone G (excessively humid). The mayor part of all forests tends to be in zone F (38.1% in year 2050; and 28.8% in year 2070) and in zone E (37.8% in year 2050; and 49.2% in year 2070). The major part of north-western and western Slovenia will have moderately arid (zone B) to moderately humid climate (zone D) (Table 4.2).

Table 4.2. Total forest areas over vulnerability zones in 2000, 2050 and 2070, Slovenia.

Year, RCP	A		B		C		D		E		F		G	
	thous.ha	%	thous.ha	%	thous.ha	%	thous.ha	%	thous.ha	%	thous.ha	%	thous.ha	%
2000	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.1	80.9	7.4	212.3	19.4	800.7	73.1
2050 RCP 2.6	0.0	0.0	0.0	0.0	26.4	2.4	44.2	4.0	193.0	17.6	421.9	38.5	409.6	37.4
2070 RCP 2.6	0.0	0.0	0.0	0.0	0.1	0.0	34.5	3.1	135.7	12.4	386.0	35.2	538.9	49.2
2050 RCP 4.5	0.0	0.0	2.7	0.2	43.3	4.0	53.7	4.9	300.5	27.4	481.9	44.0	213.0	19.5
2070 RCP 4.5	0.0	0.0	17.9	1.6	51.0	4.7	77.2	7.1	406.3	37.1	429.3	39.2	113.4	10.4
2050 RCP 6.0	0.0	0.0	0.0	0.0	21.4	2.0	42.7	3.9	181.8	16.6	436.2	39.8	413.0	37.7
2070 RCP 6.0	0.0	0.0	0.0	0.0	15.5	1.4	45.4	4.1	183.6	16.8	442.0	40.4	408.7	37.3
2050 RCP 8.5	0.0	0.0	28.5	2.6	48.5	4.4	86.7	7.9	414.2	37.8	417.4	38.1	99.8	9.1
2070 RCP 8.5	0.0	0.0	34.5	3.2	53.7	4.9	116.3	10.6	538.6	49.2	315.9	28.8	36.2	3.3

4.4.3. Lithuania

In current climate (1950-2000) all Lithuanian forests are in zone D (moderately humid climate) (41.3%) and E (humid climate) (58.7%) (Table 4.3). At the optimistic scenario RCP2.6, occur four climate zones: moderately arid (B), slightly humid (C), moderately humid (D) and humid (E) climate, which will cover 20.8%, 60.8%, 14.2% and 4.2% forests respectively, at the period of 2050. At the period of 2070, area of slightly humid climate will increase, while moderately arid vice versely. According to scenario RCP4.5, the climate zone E will shift out of Lithuania, however, semiarid climate is forecasted predicted in 1.4% of the existing forest area. Moderately arid climate has been forecasted as dominant in both periods (2050 and 2070). According to scenario RCP6.0 in Lithuania will be B, C, D and E climate zones. Slightly humid climate will be dominant in both periods (2050 and 2070). Significant differences between two periods was not found. At the pessimistic scenario RCP8.5, A, B, C and D zones are expected. The largest part of forest areas is expected in zone B (about 73%). About 4% of the existing forest area will be situated in the semiarid zone.

Total 4.3. Forest areas over vulnerability zones in 2000, 2050 and 2070, Lithuania.

Year, RCP	A		B		C		D		E	
	thous. ha	%	thous. ha	%	thous. ha	%	thous. ha	%	thous.ha	%
2000	0.0	0.0	0.0	0.0	0.0	0.0	851.1	41.3	1206.7	58.7
2050 RCP 2.6	0.0	0.0	412.7	20.8	1201.2	60.8	280.4	14.2	82.6	4.2
2070 RCP 2.6	0.0	0.0	120.1	5.9	1421.8	69.9	349.3	17.2	142.9	7.0
2050 RCP 4.5	29.4	1.4	1493.9	73.4	243.0	12.0	267.7	13.2	0.0	0.0
2070 RCP 4.5	0.0	0.0	1266.6	62.3	448.3	22.0	319.1	15.7	0.0	0.0
2050 RCP 6.0	0.0	0.0	542.6	26.7	1121.1	55.1	350.2	17.2	20.1	1.0
2070 RCP 6.0	0.0	0.0	541.2	26.6	1120.5	55.1	352.1	17.3	20.3	1.0
2050 RCP 8.5	86.2	4.2	1494.4	73.5	310.5	15.3	142.9	7.0	0.0	0.0
2070 RCP 8.5	74.3	4.1	1485.3	73.0	320.1	15.7	144.3	7.1	0.0	0.0

4.4.4. Ukraine (pilot area)

The total pilot area is about 8.2 mln. ha, from which the forest area is 1.095 mln.ha. Forest fragmentation is rather big. The forest cover in Sumy region is 17,8 %, and in Lugansk is 11 %. As the data source during the project the forest taxation data base, containing only data on forests subordinated to State Agency of Forest resources of Ukraine (approx. 70% of total area of forests in the pilot area) was used.

In current climate (1950-2000) on the pilot territory there are three climate zones: B, C and D (Table 4.4) (Buksha et al. in press) . In B zone of moderately arid climate, there are 308.3 thous. ha of forests (38.8%), 130 thous. ha of them are coniferous (mainly Scotch pine), and 177,1 thous. ha – deciduous. In C zone of slightly humid climate, the total area of forests amounts 247.2 thous. ha (31.2%) including 711.6 thous. ha of coniferous and 175.4 thous. ha of deciduous forests. In D zone of moderate humid climate that is characterized by medium vulnerability level for forest growing, 238.4 thous. ha of forests (30%) are located, coniferous stands are slightly prevailing (124 thous. ha).

Table 4.4. Total forest areas over vulnerability zones in 2000, 2050 and 2070, Ukraine (pilot area).

Year, RCP	A		B		C		D	
	thous.ha	%	thous.ha	%	thous.ha	%	thous.ha	%
2000	0	0	308.4	38.8	247.3	31.2	238.4	30.0
2050 RCP 2.6	167.8	21.1	626.2	78,9	0	0	0	0
2070 RCP 2.6	29.2	3.7	502.3	63.2	262.6	33.1	0	0
2050 RCP 4.5	218.9	27.6	575.1	72.4	0	0	0	0
2070 RCP 4.5	336.3	42.4	457.7	57.6	0	0	0	0
2050 RCP 6.0	409.5	51.6	384.5	48.4	0	0	0	0
2070 RCP 6.0	135.2	17.0	658.7	83.0	0	0	0	0
2050 RCP 8.5	667.6	84.1	126.4	15.9	0	0	0	0
2070 RCP 8.5	794.0	100	0	0	0	0	0	0

According to all scenarios till 2050 significant redistribution of areas of vulnerability zones is expected, disappearance of the most favorable zones C and D for forest growth and change of climate conditions to more arid and unfavorable – appearance of zone A and increasing of B zone area. Till 2070 these processes will continue, except RCP2.6 and RCP6.0 where slight increasing of precipitation level will cause less aridization comparing to 2050.

At the optimistic scenario RCP2.6, the main part of forests will be in zone B: 78.9% in 2050 and 63.2% in 2070; A zone of semiarid climate will appear in southern part. Only in this scenario the C zone will remain by 2070 (33.1% of forest area). At the RCP4.5 and RCP6.0, the expected forest areas in zone B will vary from 48% to 72.4%, the share of forests in zone A will increase and make from 17% to 51.6%.

According to the pessimistic scenario RCP8.5, almost all forest areas at the pilot area will be in zone A (semiarid climate): 84.1% in 2050 and 100% in 2070 (Table 4.4). So at RCPs by 2050 and 2070 almost all forests at the pilot area will be under unfavorable climatic conditions (zones A and B – zones of high vulnerability level).

4.5. Forest tree species over vulnerability zones

4.5.1. Bulgaria

Currently, the total number of the forest tree species in Bulgaria is 158 of which 119 deciduous and 39 coniferous (Figure 4.24).

Figure 4.24. Forest map of Bulgaria in current climate (1950-2000) (*deciduous forests in green color and coniferous forests in turquoise color*) (Source: Executive Forestry Agency, Sofia).

The distribution of the areas by tree species and vulnerability zones in 2000 and 2050 (RCP2.6 and RCP8.5) is given in Table 4.5. The examined scenarios are optimistic (RCP2.6) and pessimistic (RCP8.5). The year of investigation is 2000, corresponding to current climate, and the nearest future period in 2050, which retains similar trends for the following period to 2070. The area of different tree species in most favorable vulnerable zones D, E and F is compared with the total area of the corresponding tree species.

Table 4.5. Distribution of the area of forest tree species (ha) over vulnerability zones in 2000 and 2050 (RCP2.6 and RCP8.5), Bulgaria.

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

N o.	Year/RCP; Zones	A	B	C	D	E	F	G	D+E+F	* %
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)										
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 sp. (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

The most common tree species of the coniferous forests is *Pinus sylvestris* L. (Scotch pine) that builds 51.7% of them. 60.7% of Scotch pine forests are part of the most favorable vulnerability zones D, E and F (900-1600 m a.s.l.) in 2000. At the RCP2.6 (2050), the expectation is that the area will decrease to 39.21% in the same zones. At the RCP8.5 (2050), 8.3% of Scotch pine forests will be in the favorable 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 a.s.l.

The most common tree species of the deciduous forests are *Quercus* sp (Oaks) that builds 48.8% of them. 12.5% of Oaks forests are part of the most favorable vulnerability zones D, E and F in 2000. Part of the Oaks forests grow 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 the Oaks area haven‘t any problems with water supply. At the RCP2.6 (2050), 24% of Oaks forests will grow in favorable conditions (zones C, D ,E , F).

The second important tree species of the deciduous forests is *Fagus sylvatica* L. (Beach) that builds 20.9% of them. 73.3% of the area of the Beach forests are part of zones D, E and F in 2000. The expectation is that 42.2% of the Beach forests area will be in favorable 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 the Bulgarian forests to drought.

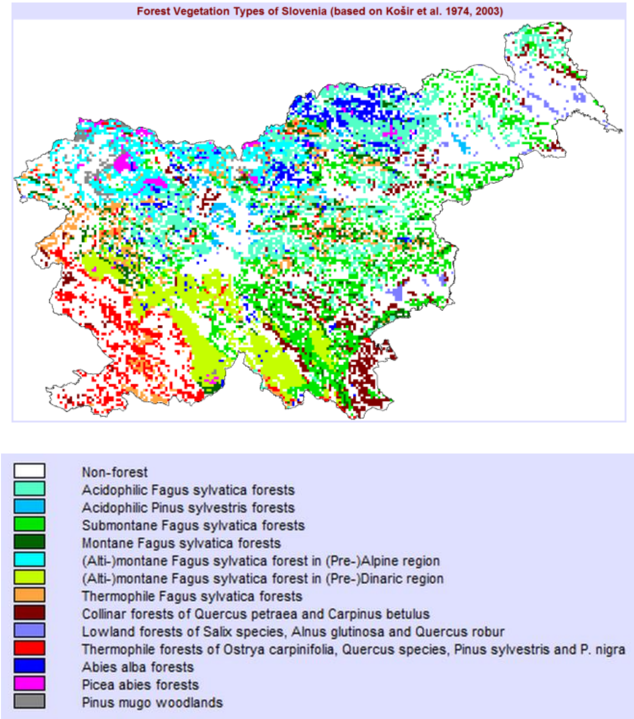
4.5.2. Slovenia

For the purposes of this analysis the original map of forest communities (Košir et al. 1974, 2003) was reclassified into 13 forest types and 1 km^2 raster resolution (Table 4.6, Figure 4.25).

Table 4.6. Description of the forest vegetation types in Slovenia.

1	Acidophilic *Fagus sylvatica* forests
2	Acidophilic *Pinus sylvestris* forests
3	Submontane *Fagus sylvatica* forests
4	Montane *Fagus sylvatica* forests
5	(Alti-)montane *Fagus sylvatica* forest in (Pre-)Alpine region
6	(Alti-)montane *Fagus sylvatica* forest in (Pre-)Dinaric region
7	Thermophile *Fagus sylvatica* forests
8	Collinar forests of *Quercus petraea* and *Carpinus betulus*
9	Lowland forests of *Salix* species, *Alnusglutinosa* and *Quercus robur*
10	Thermophile forests of *Ostrya carpinifolia*, *Quercus* species, *Pinus sylvestris* and *P. nigra*
11	*Abies alba* forests
12	*Picea abies* forests
13	*Pinus mugo* woodlands

Figure 4.25. Distribution of forest vegetation types in current climate (1950-2000) in Slovenia.



Diverse vegetation patterns have been recognised in Slovenian forests: in periodically flooded lowlands, in narrow strips along the rivers and brooks, forests of willows (*Salix* sp.), alders (*Alnus glutinosa* (L.) Gaertn., *Alnus incana* (L.) Moench), ashes (*Fraxinus excelsior* L., *Fraxinus oxycarpa* Willd.), and common oak (*Quercus robur* L.) grow. In the hilly areas above the floodplains, where for the most part the forests have now been converted to farmland, is the region of mixed forests of sessile oak (*Quercus petraea* (Matt.) Liebl.) and hornbeam (*Carpinus betulus* L.). In the mountainous areas, these change gradually into forests with predominantly beech (*Fagus sylvatica* L.) trees. The beech forests with mixtures of different broadleaves and conifers cover the major part of the forested area of the country, and the Dinaric forest of common beech and silver fir (*Abies alba* Miller) is one of the most extensive forest communities in the country. In the Alpine region, together with Norway spruce (*Picea abies* (L.) Karst.), and European larch (*Larix decidua* Mill.), more or less pure beech forests reach up to the belt of the dwarf mountain pine (*Pinus mugo* Turra) in the Dinaric range (Figure 4.25).

On extremely warm, steeper sites all over the country, mainly on limestone and dolomite terrain, forests and woodland of different thermophile tree species (e.g. *Ostrya carpinifolia* Scop., *Fraxinus ornus* L. *Quercus pubescens* Willd.) extend.

In its natural range, spruce grows more abundantly only in the Alpine area, on the high plateaus of the Julian Alps, and in the Kamnik-Savinja Alps and Karavanke Mountains. To a small extent, natural spruce forests grow in cold valleys and sinkholes in the Dinaric region. However, they also grow on Pohorje Mountain, where they are, for the most part, not native, and throughout the country in which they have been disseminated, mainly by man, for their useful wood. In these areas, the spruce is much more sensitive to the rigours of the weather and to the more widespread bark beetles.

Beside woodlands of dwarf mountain pine in the high-alpine zone, the pine forests are composed of Scots pine (*Pinus sylvestris* L.) and of Austrian pine (*Pinus nigra* Arnold). The Scots pine can be found throughout the interior of the country on the poorest soils, and Austrian pine forests grow on some of the steeper slopes of the continental part and extend over the larger part of south-western Slovenia, in the Karst region. Centuries ago, the deciduous forests of this region were degraded by logging, burning and pasturing. Intensive reforestation and afforestation of the Karst in Sub-Mediterranean region with Austrian pine started in the middle of the 19th century.

The distribution of the areas by forest vegetation types and vulnerability zones in 2000 and 2050 (RCP2.6 and RCP8.5) is given in Table 4.7. The examined scenarios are optimistic (RCP2.6) and pessimistic (RCP8.5). The year of investigation is 2000, corresponding to current climate, and the nearest future period in 2050, which retains similar trends for the following period in 2070. The area of different forest vegetation types in vulnerable zones D, E and F is compared with the total area of the corresponding forest vegetation type. The studied forest vegetation types have been classified according to the vulnerability zones as follows: zone A - very high vulnerability level; zone B - high vulnerability level; zones C and D - medium vulnerability level; zones E and F - low vulnerability level; zone G - medium to very high vulnerability level.

Comparing relative changes among 13 vegetation types from the period 1950-2000 to the year 2050, the significant changes of vulnerability level have been identified in Table 6.7. The significant decrease of excessively humid area (zone G) is forecasted for all forest vegetation types in Slovenia. The tendency to less humid or even moderately arid conditions (between zone C and zone B) has been detected for different forest types (Table 4.7). The significant shift to more arid conditions is expected in vegetation type 1 (Acidophilic *Fagus sylvatica* forests), vegetation type 3 (Submontane *Fagus sylvatica* forests), vegetation type 8 (Collinar forests of *Quercus petraea* and *Carpinus betulus*) and vegetation type 9 (Lowland forests of *Salix* species, *Alnus glutinosa* and *Quercus robur*). These forests mostly cover lowland and hilly areas in the north-eastern and eastern part of Slovenia (Table 4.7).

Table 4.7. Distribution of area of forest tree species (ha) over vulnerability zones in 2000 and 2050 (RCP2.6 and RCP8.5), Slovenia.

No.	Year/RCP; Zones	A	B	C	D	E	F	G	D+E+F	*%
Total forest area (1 095 117 ha; 100 %)										
1.	2000	0	0	0	1198	80934	212251	800734	294383	26.7
2.	2050, RCP 2.6	0	0	26384	44207	193022	421937	409567	659166	59.8
3.	2050, RCP 8.5	0	28477	48534	86680	414215	417404	99807	918299	83.4
1. Acidophilic *Fagus sylvatica* forests 208 894 ha; 19.1 % of total forest area)										
1.	2000	0	0	0	0	19831	48192	140871	68023	32.4
2.	2050, RCP 2.6	0	0	6238	13570	46676	96511	45899	156757	14.2
3.	2050, RCP 8.5	0	7228	13772	22105	102395	56903	6491	181403	16.5
2. Acidophilic *Pinus sylvestris* forests (21 678 ha; 2.0 % of total forest area)										
1.	2000	0	0	0	0	2000	4600	15078	6600	30.4
2.	2050, RCP 2.6	0	0	0	692	6139	14589	258	21420	98.7
3.	2050, RCP 8.5	0	0	2519	2004	16187	968	0	19159	88.3
3. Submontane *Fagus sylvatica* forests (208 373 ha; 19.0 % of total forest area)										
1.	2000	0	0	0	200	29889	56477	121807	86566	41.4
2.	2050, RCP 2.6	0	0	4885	22982	52512	89314	38680	164808	78.8
3.	2050, RCP 8.5	0	5236	25537	28368	84804	64074	354	177246	84.7
4. Montane *Fagus sylvatica* forests (69 109 ha; 6.3 % of total forest area)										
1.	2000	0	0	0	0	77	8974	60058	9051	13.0
2.	2050, RCP 2.6	0	0	0	74	10229	36017	22789	46320	66.6
3.	2050, RCP 8.5	0	0	153	4197	32175	30434	2150	66806	96.0
5. (Alti-)montane *Fagus sylvatica* forest in (Pre-)Alpine region. (84 749 ha; 7.7 % of total forest area)										
1.	2000	0	0	0	0	0	0	84749	0	0.0
2.	2050, RCP 2.6	0	0	0	0	36	6939	77774	6975	8.2
3.	2050, RCP 8.5	0	0	0	0	4030	36748	43971	40778	47.7
6. (Alti-)montane *Fagus sylvatica* forest in (Pre-)Dinaric region (132 883 ha; 12.1% of total forest area)										

1.	2000	0	0	0	0	0	100	132783	100	0.1
2.	2050, RCP 2.6	0	0	0	0	0	18928	113955	18928	14.2
3.	2050, RCP 8.5	0	0	0	0	4351	119776	8756	124127	93.3
7. Thermophile *Fagus sylvatica* forests (84 798 ha; 7.7 % of total forest area)										
1.	2000	0	0	0	0	0	10386	74412	10386	12.1
2.	2050, RCP 2.6	0	0	0	0	5842	45298	33658	51140	59.8
3.	2050, RCP 8.5	0	0	0	1360	35680	43817	3941	80857	94.6
8. Collinar forests of *Quercus petraea* and *Carpinus betulus* (84 982 ha; 7.8 % of total forest area)										
1.	2000	0	0	0	465	13214	45586	25717	59265	69.2
2.	2050, RCP 2.6	0	0	7420	4095	35019	35628	2820	74742	87.2
3.	2050, RCP 8.5	0	7907	3834	12912	51748	8581	0	73241	85.5
9. Lowland forests of *Salix* species, *Alnus glutinosa* and *Quercus robur* (18 045 ha; 1.6 % of total forest area)										
1.	2000	0	0	0	533	11537	4600	1375	16670	91.1
2.	2050, RCP 2.6	0	0	7841	2789	6100	1116	199	10005	54.7
3.	2050, RCP 8.5	0	8106	2638	5826	1098	277	100	7201	39.3
10.Thermophile forests of *Ostrya carpinifolia*, *Quercus* species, *Pinus sylvestris* and *P. nigra* (78 190 ha; 7.1 % of total forest area)										
1.	2000	0	0	0	0	4386	21136	52668	25522	32.4
2.	2050, RCP 2.6	0	0	0	5	14346	43613	20226	57964	73.6
3.	2050, RCP 8.5	0	0	81	5152	40629	30178	2150	75959	96.4
11. *Abies alba* forests (66 474 ha; 6.1 % of total forest area)										
1.	2000	0	0	0	0	0	12200	54274	12200	18.3
2.	2050, RCP 2.6	0	0	0	0	16016	32902	17556	48918	73.2
3.	2050, RCP 8.5	0	0	0	4756	40243	18994	2481	63993	95.8
12. *Picea abies* forests (20 166 ha; 1.8 % of total forest area)										
1.	2000	0	0	0	0	0	0	20166	0	0.0
2.	2050, RCP 2.6	0	0	0	0	107	802	19257	909	4.4
3.	2050, RCP 8.5	0	0	0	0	766	4830	14570	5596	27.2
13. *Pinus mugo* woodlands 16 776 ha; 1.5 % of total forest area)										
1.	2000	0	0	0	0	0	0	16776	0	0.0
2.	2050, RCP 2.6	0	0	0	0	0	280	16496	280	1.6
3.	2050, RCP 8.5	0	0	0	0	109	1824	14843	1933	11.3

*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

4.5.3. Lithuania

Uneven distribution of tree species is determined by diverse distribution of forest site types according to soil humidity and fertility. The poor soils of normal humidity compose 20.6% of forest lands, fertile and very fertile temporally over moisted soils – 25.9%. About 8% of forest area occupy undrained peatlands. In general the Scots pine stands prevail in southeast part of Lithuania and mixed spruce and birch forests – in central and west parts. In present in the territory of the Lithuania dominate low (58.7%) and conditionally low (41.4%) vulnerability level of forests.

The distribution of forest tree species is presented in Figure 4.26 (0.25 km^2 raster-forest block size). In current climate (1950-2000) coniferous stands prevail in Lithuania.

The forecasted climate changes are unfavorable for all tree species (especially for *Picea abies* and partly for Scots pine (Ozolincius et al. 2014).

Distribution of the area of forest tree species (ha) according to vulnerability zones in 2000 and 2050 (RCP2.6 and RCP8.5), has been predicted and presented in Table 4.8. Decrease of the total forest area of moderately humid (D), humid (E) and very humid (F) climate predicted for both optimistic and pessimistic scenarios. According to scenario RCP2.6, about 17% of coniferous and 20% of deciduous forests will cover D, E and F zones (in 2050). According to scenario RCP8.5 about 6% of coniferous and 8% of deciduous forests will cover D, E and F zones (in 2050). However according to optimistic scenario (RCP2.6) slightly humid climate zone will be dominant at the existing Lithuanian forest area, while moderately arid zone - according to pessimistic scenario. The tree species in Lithuania have a different location. *Pinus sylvestris* is more common in South-East, *Picea abies* in North-West, deciduous in middle of Lithuania.

Figure 4.26. Distribution of forest tree species in current climate (1950-2000) in Lithuania.

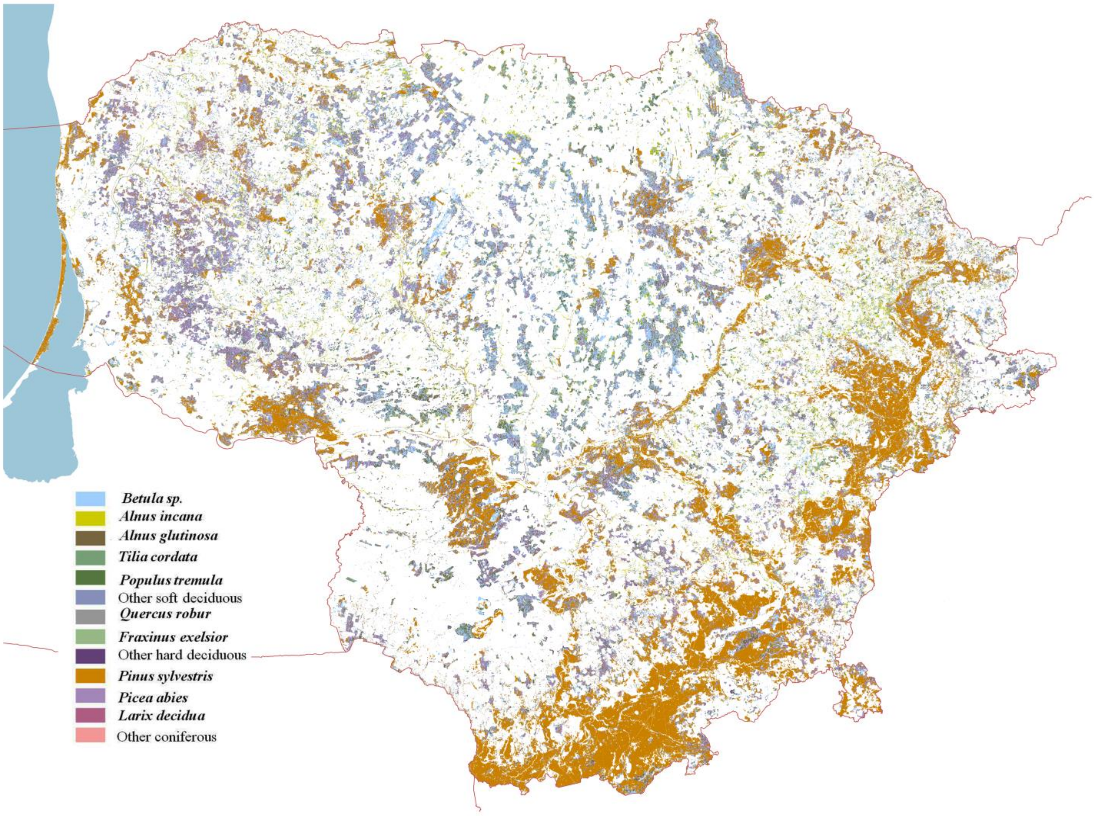


Table 4.8. Distribution of the area of forest tree species (ha) over vulnerability zones in 2000 and 2050 (RCP2.6 and RCP8.5), Lithuania.

No.	Year/RCP; Zones	A	B	C	D	E	F	G	D+E+F	* %
Total forest area (2 057 714 ha; 100%)										
1.	2000	0.0	0.0	0.0	851100	1233700	0.0	0.0	2057714	100.0
2.	2050, RCP 2.6	0.0	412657	1201191	280442	82566	0.0	0.0	363008	18.4
3.	2050, RCP 8.5	86222	1494436	310491	142876	0.0	0.0	0.0	142876	7.0
Coniferous (1 153 310 ha; 56,0% of total forest area)										
1.	2000	0.0	0.0	0.0	731727	421583	0.0	0.0	1153110	100.0
2.	2050, RCP 2.6	0.0	194765	729665	145438	44367	0.0	0.0	189805	17.0
3.	2050, RCP 8.5	53977	844822	165631	72610	0.0	0.0	0.0	72610	6.4
Pinus sylvestris L. (724 214 ha; 35,2% of total forest area)										
1.	2000	0.0	0.0	0.0	474915	249299	0.0	0.0	724214	100.0
2.	2050, RCP 2.6	0.0	113921	508394	61502	17018	0.0	0.0	78520	11.2
3.	2050, RCP 8.5	42817	576507	69109	20888	0.0	0.0	0.0	20888	2.9
Picea abies (L.) Karst. (429 096 ha; 20.9% of total forest area)										
1.	2000	0.0	0.0	0.0	256812	172284	0.0	0.0	429096	100.0
2.	2050, RCP 2.6	0.0	80844	221251	83936	27349	0.0	0.0	111285	26.9
3.	2050, RCP 8.5	11160	268315	96522	51722	0.0	0.0	0.0	51722	12.1
Deciduous (884 173 ha; 44,0% of total forest area)										
1.	2000	0.0	0.0	0.0	464777	256204	0.0	0.0	884173	100.0
2.	2050, RCP 2.6	0.0	210612	462857	132422	37678	0.0	0.0	170100	20.2
3.	2050, RCP 8.5	30488	636837	140963	69254	0.0	0.0	0.0	69254	8.0
Betula sp. (460 152 ha; **22.4% of total forest area)**										
1.	2000	0.0	0.0	0.0	246259	213893	0.0	0.0	460152	100.0
2.	2050, RCP 2.6	0.0	102070	249146	67111	20421	0.0	0.0	87532	19.9
3.	2050, RCP 8.5	12339	333832	75064	35552	0.0	0.0	0.0	35552	7.8
Populus tremula L. (81933 ha; 4.0% of total forest area)										
1.	2000	0.0	0.0	0.0	35736	46197	0.0	0.0	81933	100.0
2.	2050, RCP 2.6	0.0	23567.3	41917.3	9878.0	2329.0	0.0	0.0	12207,0	15.7
3.	2050, RCP 8.5	2552	63297	10776	5083	0.0	0.0	0.0	5083	6.2

No.	Year/RCP; Zones	A	B	C	D	E	F	G	D+E+F	* %
Alnus glutinosa (L.) Gaertn. (144 491 ha; 7.0% of total forest area)										
1.	2000	0.0	0.0	0.0	69797	74694	0.0	0.0	144491	100.0
2.	2050, RCP 2.6	0.0	44428.8	73832.3	18806.5	3200.0	0.0	0.0	22006,5	15.7
3.	2050, RCP 8.5	12606	105868	16281	8205	0.0	0.0	0.0	8205	5.7
Alnus incana (L.) Moench. (127 609 ha; 6.2% of total forest area)										
1.	2000	0.0	0.0	0.0	80525	47084	0.0	0.0	127609	100.0
2.	2050, RCP 2.6	0.0	17632.3	72524.8	21529.5	8029.0	0.0	0.0	29558,5	24.7
3.	2050, RCP 8.5	23	88416	24714	13560	0.0	0.0	0.0	13560	10.7
Quercus robur L. (41014 ha; 2.0% of total forest area)										
1.	2000	0.0	0.0	0.0	21790	19224	0.0	0.0	41014	100.0
2.	2050, RCP 2.6	0.0	12937.0	13352.3	10458.3	2729.4	0.0	0.0	13187,7	33.4
3.	2050, RCP 8.5	1826	24027	9508	5066	0.0	0.0	0.0	5066	12.5
Fraxinus excelsior L. (28974 ha; 1.4% of total forest area)										
1.	2000	0.0	0.0	0.0	10670	18304	0.0	0.0	28974	100.0
2.	2050, RCP 2.6	0.0	9977.5	12084.8	4639.3	970.4	0.0	0.0	5609,7	20.3
3.	2050, RCP 8.5	1142	21397	4620	1788	0.0	0.0	0.0	1788	6.2
Other species (20231 ha; 1.0% of total forest area)										
1.	2000	0.0	0.0	0.0	10117	10114	0.0	0.0	20231	100.0
2.	2050, RCP 2.6	0.0	7279.5	8688.7	2582.3	521.5	0.0	0.0	3103.5	16.3
3.	2050, RCP 8.5	1757	12777	3897	1012	0.0	0.0	0.0	1012	5.2

*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

4.5.4. Ukraine (pilot area)

Forest stands of the pilot territory include over 35 main forest tree species, but only two of them – *Quercus robur* L. and *Pinus sylvestris* L., are dominating and cover 83% of all forest area. Main tree species areas distribution by vulnerability zones in 2000 and for two scenarios in 2050 (optimistic RCP2.6 and pessimistic RCP8.5) is given in Table 4.9.

Table 4.9. Distribution of the area of forest tree species (ha) over vulnerability zones in 2000 and 2050 (RCP2.6 and RCP8.5), in Ukraine (pilot area).

No.	Year/RCP; Zones	A	B	C	D	E	F	G	D+E+F	* %
Total forest area (793 964,6 ha; 100%)										
1.	2000	0	308346,6	247248,1	238369,9				238369,9	30,0
2.	2050, RCP 2.6	167810,7	626153,9	0	0				0	0
3.	2050, RCP 8.5	667546,6	126418	0	0				0	0
Coniferous (330 714,3 ha; 41,7% of total forest area)										
1.	2000	0	131202,2	71837,8	127674,3				127674,3	38,6
2.	2050, RCP 2.6	72887,5	257826,8	0	0				0	
3.	2050, RCP 8.5	265627,8	65086,5	0	0				0	
Pinus sylvestris L. (326 593,8 ha; 41,1 % of total forest area)										
1.	2000	0	128478,2	71665,8	126449,8				126449,8	38,7
2.	2050, RCP 2.6	71457	255136,8	0	0				0	
3.	2050, RCP 8.5	262387,9	64205,9	0	0				0	
Other coniferous (4120,5 ha; 0,5 % of total forest area)										
1.	2000	0	2724	172	1224,5				1224,5	29,7
2.	2050, RCP 2.6	1430,5	2690	0	0				0	
3.	2050, RCP 8.5	3239,9	880,6	0	0				0	
Deciduous (463250,3 ha; 58,3% of total forest area)										
1.	2000	0	177144,4	175410,3	110695,6				110695,6	23,9
2.	2050, RCP 2.6	94923,2	368327,1	0	0				0	
3.	2050, RCP 8.5	401918,8	61331,5	0	0				0	
Quercus robur L. (334389,7 ha; 42,1% of total forest area)										
1.	2000	0	103419,2	155819,9	75150,6				75150,6	22,5
2.	2050, RCP 2.6	55686	278703,7	0	0				0	
3.	2050, RCP 8.5	296886,9	37502,8	0	0				0	
Fraxinus excelsior L. (50588,7 ha; 6,4 % of total forest area)										

No.	Year/RCP; Zones	A	B	C	D	E	F	G	D+E+F	* %
1.	2000	0	24356,5	8971,1	17261,1				17261,1	34,1
2.	2050, RCP 2.6	10363,5	40225,2	0	0					
3.	2050, RCP 8.5	40706,2	9882,5	0	0					
Robinia pseudoacacia L. (23702 ha; 3,0 % of total forest area)										
1.	2000	0	21338	2100	264				264	1,1
2.	2050, RCP 2.6	9890,3	13811,7	0	0					
3.	2050, RCP 8.5	23455,2	246,8	0	0					
Other deciduous (54569,9 ha; 6,9 % of total forest area)										
1.	2000	0	28030,7	8519,3	18019,9				18019,9	33,0
2.	2050, RCP 2.6	18983,4	35586,5	0	0				0	
3.	2050, RCP 8.5	40870,5	13699,4	0	0				0	

*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

Pinus sylvestris L. (Scotch pine) is the most wide spread coniferous species at the studied area, it covers 41% of total forest area. The large part of forest stands (especially Scotch pine) is artificial. About one third of pine forests is pure (tree species composition includes only pine) (about 116.1 thous. ha). In current climatic conditions Scotch pine forests are presented in all climatic zones (B, C and D). 30% of them are located in the most favorable zone D – these forests are located at the southern border of Scotch pine natural range. According to the RCPs, it is expected that by 2050 all pine forests will be in high vulnerability zone (A and B), so it is possible shifting of the natural range of *Pinus sylvestris* L. to the north.

Other coniferous are represented by *Picea abies* (L.) Karst. 100% of which is in D zone outside the natural range, and *Pinus nigra ssp. pallasiana* mostly located in B zone.

Among deciduous forests the dominating main tree species is *Quercus robur* L. (Oak) that makes 72.2% of them. In current climate 69.% of the Oak forest stands are located in favorable conditions, 22.2% of them are in D zone, and 46,6% – in C zone. According to all RCPs by 2050 all Oak forests will grow in unfavorable conditions (zones A and B), so it is possible that natural range of *Quercus robur* L. at the pilot territory will be narrowed and fragmentated.

Comparatively big area is covered by *Fraxinus excelsior* L. forest stands (10.9% from deciduous) and introduced *Robinia pseudoacacia* L. (5% from decidous). These two species are more xerophytic and mostly grow in moderately arid climate (B zone) in present conditions. According to RCP2.6 by 2050 20.5% of Ash stands will be under unfavorable conditions (zone A), at RCP8.5 – 80.6%.

Forests at the pilot area are rather vulnerable to expected drought: due to their species composition, comparatively high percent of pure pine stands that have a big risk of fires or insects outbreaks, so there is a big threat of loss of these forests. Another problem is in low diversity of forests – big percent of oak and pine stands at studied area. It is possible that in new climatic conditions main forest species will be substituted by secondary more xerophytic species or steppe vegetation. These changes in tree species composition will cause decreasing of sustainability, biodiversity, productivity and forest areas. Rather big probability of increasing of share of introduced species areas, as *Robinia pseudoacacia* L., *Fraxinus lanceolata* Borkh. (F. viridis Michx.), *Quercus rubra* L., as well as invasive *Acer negundo* L., that will also cause losses in biodiversity and stand productivity. In current climate spruce (*Picea abies* (L.) Karst.) forest stands are growing only in moderately humid climate so future aridization of climate will cause degradation of these forests.

5. CONCLUSIONS

There is a drought impact on forests in four GWP CEE countries but it is different on tree species. Based on the analyses done in the forest demonstration project of IDMP CEE, the following conclusions can be made:

Bulgaria

✓ In 1950-2000, most widely distributed forest areas with mean annual air temperature from 11^0C to 4^0C at altitude from 500-600 to 1600-1800 m a.s.l. had temperate and cool mountain climate. In 2050 the warming in the country is expected to be between 0.75^0C -1.5^0C (RCP2.6) and 2.5^0C -3.5^0C (RCP8.5), but in 2070 would be higher - between 1.5^0C -2.5^0C (RCP2.6) and 3.5^0C -4.5^0C (RCP8.5) in 2070.

✓ Precipitation in current climate (1950-2000) 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 a.s.l. is 720-1100 mm. At the RCP2.6 in 2050-2070, no major precipitation changes are expected. At the RCP8.5 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.

- ✓ In current climate (1950-2000), most forests (63.7% of the area) fall in zones C, D, E, F i.e. under more favorable zones of vulnerability. 36.3% of the forest areas are in unfavorable zones A, B and G. At the RCP2.6, the expectation is about 56.3% of the forest area in 2050 and 53.8% in 2070 to fall in unfavorable areas of vulnerability. At the RCP8.5, the rate of unfavorable vulnerability zones will increase to 84.8% in 2050 and 89.5% in 2070.
- ✓ In current climate (1950-2000) the 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.
- ✓ The forest formations of the group *Quercus* sp. are widely available from 0 to 1200 m a.s.l. 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.
- ✓ In current climate (1950-2000), 96% of the forests of *Fagus sylvatica* are in favorable zones of vulnerability for them (C, D, E, F) - from 700 to 1600 m a.s.l. It is expected that the climate conditions at higher altitudes wouldn't be changed seriously in 2050-2070, but at low altitudes *Fagus sylvatica* will be at risk in drought periods.
- ✓ In current climate (1950-2000), 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 a.s.l. in 2050-2070 will decrease these tree species, introduced outside of its natural habitat.

Slovenia

- ✓ Slovenia is a transitional climate area between the Mediterranean Sea, the Alps, the Dinaric Mountains and the Pannonian Basin. As a consequence, its climate demonstrates wide local climatic variability and fairly large gradients.
- ✓ Slovenia's climate is extremely diverse. Near the coast, the prevailing type of climate is sub-Mediterranean, in mountains Alpine, while the continental climate prevails in the flat parts of eastern Slovenia. The maximum annual precipitation is in the northwest in the Julian Alps, where annual precipitation can exceed 3000 mm. On the coast, the annual precipitation usually does not reach 1000 mm, increases towards the top of the Alpine-Dinaric mountain ranges, and then decreases with the increasing distance from the sea towards the northeast. In the extreme northeast the precipitation is usually below 800 mm per year.
- ✓ During the period 1951–2007, mean annual temperatures in Slovenia have increased significantly by 0.15 to 0.29°C per decade. The strong warming in summer and spring could be enhanced by drier shallow soils due to the decreased winter precipitation in Slovenia.
- ✓ Using the WorldClim data, the calculated annual air temperature in period 1950-2000 in Slovenia is between -1.2^{0}C and 14.5^{0}C. In current climate the mean annual air temperature is 8.9^{0}C. IPCC AR5 based air temperature forecast according to RCPs show the significant increase of temperature in future. Till year 2070, the climate in Slovenia will be warmer for 2.8^{0}C at RCP2.6 to 6.2^{0}C at RCP8.5.
- ✓ Based on WorldClim data, the calculated annual precipitation in the period 1950-2000 in Slovenia is between 777 mm and 1404 mm. In current climate the mean annual precipitation is 1182 mm. At the RCP8.5, the most significant reduction of the precipitation amount is expected in the north-eastern part of Slovenia, and in Dinaric mountains and Alps. However, the decrease of precipitation amount and the changes of precipitation regime will affect different types of forest vegetation.
- ✓ In current climate the values of De Martonne index vary between 30 and more than 110. The lowest values were calculated for East and Northeast Slovenia (Pre-Pannonian region) and for West to Southwest Slovenia (Sub-Mediterranean region). Based on De Martonne index calculation, 73% of all Slovenian forests occur in excessively humid climate (zone G), 19% in very humid (zone F), and 7% in humid climate (zone E).
- ✓ At the RCP8.5, only 9% of all forests in Slovenia in year 2050 and 3% in year 2070 might occur in excessively humid climate (G). The mayor part of all forests tends to be in zone F and in zone E. The major part of north-western and western Slovenia will have moderately humid (zone D) to moderately arid (zone B) climate.

✓ The tendency to less humid or even moderately arid conditions (between zone C and zone B) has been estimated for different forest types. The significant shift to more arid conditions is expected in following vegetation types: Acidophilic *Fagus sylvatica* forests, Submontane *Fagus sylvatica* forests, Collinar forests of *Quercus petraea* and *Carpinus betulus* and Lowland forests of *Salix* species, *Alnus glutinosa* and *Quercus robur*. These forests mostly cover lowland and hilly areas in the north-eastern and eastern part of Slovenia.

Lithuania

✓ Most significant increase of air temperature is expected in 2050 as well as in 2070 according to pessimistic climate change scenario RCP8.5. Average annual air temperature will exceed 11.5^{0}C in some southwestern parts of Lithuania. As a rule, the least increase in temperature should be according to RCP2.6 scenario. However, there are some differences between scenarios RCP4.5 and RCP6.0. Greater warming (0.3-0.7^{0}C) before 2050 is estimated according to RCP4.5 scenario than according to scenario RCP6.0. After 2050 warming rate in RCP4.5 will decrease while according to scenario RCP6.0 – will increase. The most plausible climate change scenarios RCP4.5 provides average annual air temperature to be between 9.7 - 10.4^{0}C in almost all plain areas across Lithuania (central and northern part as well as coastal lowland), and between 8.8 – 9.5^{0}C in the complex terrain areas (Baltic and Samogitia highlands).

✓ Estimated changes in precipitation seem to be not as high as the temperature. Until 2050 the largest decrease in precipitation is estimated in the Central part of Lithuania (RCP2.6, RCP4.5 and RCP8.5), while scenario RCP6.0 provides an increase of annual precipitation amount particularly in the western part of Lithuania (up to 850-870 mm/year). In the later period (2070) scenarios RCP4.5, RCP6.0 and RCP8.5 show a further slight decrease in precipitation and only RCP2.6 scenario - an increase in precipitation, particularly in Žemaičių upland area (800-850 mm). The most obvious changes in the annual precipitation expected by RCP8.5 scenario - 500 to 550 mm in central part of Lithuania with minimal values in the Šešupė river upper reaches - 480 mm. The smallest changes in precipitation (compared to the current climatic conditions) would be in the western part of Lithuania.

✓ According to current climate (1950-2000), De Martonne aridity index range only 2 exist forests zones: D (moderately humid climate) - 41.3% and E (humid climate) - 58.7% in Lithuania. Therefore, forests vulnerability level is not as high. The optimistic scenario RCP2.6 tells, that four climate zones: moderately arid (B), slightly humid (C), moderately humid (D) and humid (E) climate will dominate in the future climate conditions of 2070 with forests area coverage 5.9%, 69.9%, 17.2% and 7% respectively. According to pessimistic scenario RCP8.5 also four climate zones expected: A, B, C and D, however largest part of forest areas will be situated in the moderately arid climate zone (about 73%) in 2070.

✓ In current climate (1950-2000) eight main tree species (included species which cover more than 1% of total forests area) dominate in Lithuanian forests together with about 40 less common native and introduced species. *Pinus sylvestri*s, *Betula spp.* (*Betula pendula* and *Betula pubescens*) and *Picea abies* are most abundant species, which occupy 78.1% of the forest area. The tree species in Lithuania are not evenly distributed across the territory, therefore their habitat area and vulnerability zones changes according to shift of the zones. *Pinus sylvestris* is more common in South-East, *Picea abies* in North-West, deciduous in middle of Lithuania.

✓ Expected increased aridity of future climate condition with increased in annual temperature and decreased in general precipitation will be unfavorable for conifers tree species (*Pinus sylvestri*s and *Picea abies*) in Lithuania. The abundance of these species is expected to decrease. However, climatic condition will be more suitable for some temperate broad-leaved tree species as: *Quercus robur, Fraxinus excelsior, Ulmus spp., Acer platanoides, Tilia cordata, Carpinus betulus, Fagus sylvatica.* However area of some species, such as *Alnus glutinosa,* may decrease due to less suitable habitats in the future.

Ukraine

✓ In current climate forests at the pilot territory of Ukraine grow in conditions of temperate climate with mean annual air temperature in range from 5^{0}C to 9^{0}C. It is expected significant warming of climate till 2050 and 2070: according to RCP 2.6 the air temperature will increase by 3.0^{0}C - 3.5^{0}C and by 4.5^{0}C - 6^{0}C at RCP8.5.

✓ The precipitation in current climate vary from 474 to 641 mm part of pilot territory till 2070. Scenario RCP8.5 forecasts sufficient reduction of precipitation on whole territory (by 2070-th by 54-82 mm or 11-13%). Also redistribution of precipitation within the year course is expected: reduction of precipitation during the growing season and increasing in the cold part of the year.

✓ In current climate forests are located in three climatic zones: B, C and D. In favourable climatic conditions (zones C and D) there is about 61.2% of total forest area. 38.8% of forests are in high vulnerability zone B. According to all scenarios by 2050 it is expected significant redistribution of areas of vulnerability zones, disappearence of the most favourable for forest growth C and D-zones and change of climate conditions to more arid and unfavourable – appearance of A zone and increasing of area of B zone. At RCPs by 2050 and 2070 almost all forests at the pilot territory will be under unfavorable climatic conditions (zones A and B). Only at optimistic scenario RCP2.6 the C zone will remain by 2070 - 33.1% of forest territory. At the RCP8.5 almost all forest at the pilot territory will be in unfavourable conditions – in zone A: 84.1% in 2050 and 100% in 2070.

- ✓ Forest stands of the pilot territory of Ukraine include 35 main forest tree species, but only two of them - *Quercus robur* L.and *Pinus sylvestris* L., are dominating and cover 83% of all forest area. The large part of forest stands (especially Scotch pine) is artificial. About one third of pine forests is pure (about 116.1 thous. ha).
- ✓ *Pinus sylvestris* L. (Scotch pine) forests cover 41% of total forest area. In current climatic conditions Scotch pine forests are presented in all climatic zones (B, C and D). 30% of them are located in the most favorable zone D – these forests are located at the southern border of Scotch pine natural range. According to the RCPs, it is expected that by 2050 all pine forests will be in high vulnerability zone (A and B). So due to climate change natural range of *Pinus sylvestris* L. fragmentation and shifting the north is expected.
- ✓ Deciduous forests are mostly represented by *Quercus robur* L. In current climate 69% of Oak forest stands are located in favorable conditions, 22.2% of them are in D zone, and 46,6% in C zone. At all RCP's till 2050 all these forests will grow in unfavorable conditions (zones A and B), so it is possible to expect narrowing and fragmentation of natural range of *Quercus robur* L. in pilot territory.

Determination of the forest vulnerability zones by IPCC AR5 scenarios, WorldClim data, De Martonne aridity index and national forest database shows a real danger of drought in Bulgaria, Slovenia, Lithuania and Ukraine (pilot area). Projected passing of the forest tree species from more favorable to less favorable areas of vulnerability requires implementation of adaptation measures to mitigate the drought impacts on forests.

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