Integrated Drought Management Programme
in Central and Eastern Europe

Assessment of drought impact on forest ecosystems *(activity 5.2)*

Establishment of methodology for assessment of drought impact on forest ecosystems in 2050 and 2070 *(Milestone 2)*

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WP:	**WP5**
Activity:	**Activity 5.2**
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1. Introduction - the climate in the past and present

The human kind always will be in risk with unexpected and unfavorable changes in climate as result of the influence of natural factors - terrestrial and cosmic. The cosmic factors are the solar radiation and the parameters of the Earth orbit. The terrestrial parameters are for example the movement of the Earths' poles, the changes of the Earth rotation speed and changes in the physical and geographical aspects of Earth (for example changes in the configuration of the continents, variation of the world ocean level, forming of mountain missives and others). The natural factors have influence on the common atmosphere circulation, the ocean streams and the cryosphere, and from them on the climate and its fluctuations and changes. The difference between the far and close past is that appears the risk for fast climate changes, caused by humans. Big parts of the scientists consider that the emissions of CO_2, and other gasses, thrown in the atmosphere mostly from industry and agriculture, can cause irreversible climate changes.

The life on Earth, as we know it, is possible because of the natural greenhouse effect. This phenomenon keeps our planet warm enough for physiological functioning of all living organisms. Since the life appeared for the first time, the release of natural GHGs helped the maintenance of Earths' temperature within frames that allow existence of life. If there was no greenhouse effect at all, the average planet temperatures were going to be so low that life would not be possible.

In the last years the question for the enhanced influence of the greenhouse effect and the connected with it warming of the climate is put in front line for researchers, media and decision makers. The climate change assumes global change of the climate and transition towards new balanced position, which leads to regional and local changes. According UNFCCC 1992 the climate change is a change, which directly influence the human activities, changes the composition of the global atmosphere and is observed together with the natural climate change for time periods, comparable with the periods of this change.

The Earths' climate had always been changing. Only twenty thousand years ago big part of Europe was covered by big glacier, which thickness reached 3 km. Mountain ranges as Alps and Pyrenees were covered with ice "hats". During the ice age rapid dislocations of the climate zones were observed that were result of the enlargement and decreasing of the ice cover. The last ice age was over around ten thousand years ago and the climate become soft.

As regular meteorological measuring exists since mid XIXst century, the recovery of the past climate is done by using different indirect indicators: geological (composition and structure of the sediment rocks), geomorphological (we find lake and river network evidences), paleontological (excavated flora and fauna, coral riffs), dendrology glaciological (isotope composition of the ice in the glaciers, admixtures), archeological findings, different historical sources (archives, legends and others) and so on. The analyses of such data show that:

- The increasing of the air temperature in XX^{th} century was highest in comparison with the previous centuries for the last 1000 years;
- For the period 1906-2005 the average global ground air temperature was increased with $0{,}74^{o}C$;
- The speed of increasing of the average global temperature of the ground air since 1976 is approximately three times faster than the speed of increasing for the entire XX^{th} century;
- Over 10 of the last 15 years are among the warmest for the period after the beginning of the regular instrumental meteorological observations, namely after 1850;
- 2009 is among the 10 warmest years and the decade 2000-2009 is warmer than the previous (1990-1999), 1990s is warmer than the previous 10 years period before it (1980-1989);
- The area of the snow cover in most of the world regions is decreased;
- The maximal duration of the period during which the land is frozen is decreased with approximately 7 % for the second half of XX^{th} century;
- The average date of river and lake frizzing for the last 150 years is delayed with approximately 5,8 days/century, while the date of ice melting comes with 6,5 days/century earlier;
- Since 1970s the duration and intensity of the drying is spread over vast territories especially in the tropics and sub tropics;
- In Europe, for the period of instrumental observations the average annual temperature has increased with 0,8°-l,0°C, and the last two decades are the warmest on the continent;
- From the beginning of XX^{th} century the precipitation over North Europe are increased with 10 to 40%, while the precipitations in some Southern Europe regions decreased with 20%.

2. Representative concentration pathways (RCPS)

RCPS are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC in the fifth Assessment Report (AR5). The pathways are used for climate modeling and research (Fig.1.1). They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively).

These pathways are going to be used in the project assuming pessimistic RCP (8.5) and optimistic (RCP3) scenarios.

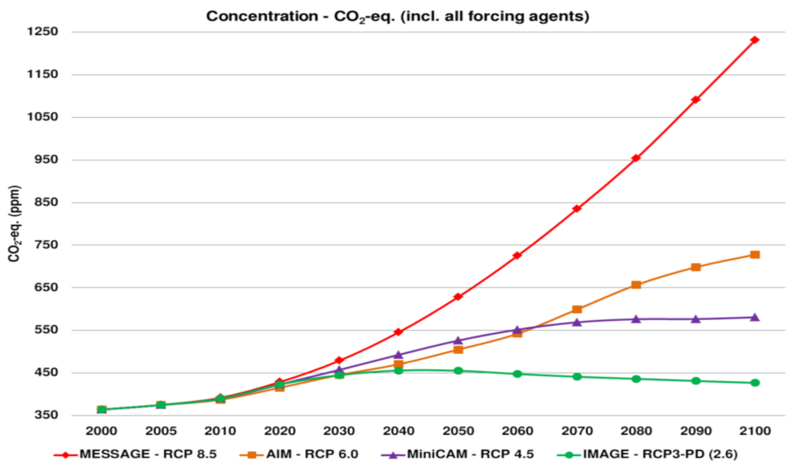


Fig.1.1. Representative concentration pathways (RCP3)

3. Climate models

The influence of the anthropogenic factor will continue to change the atmosphere composition during the entire XXI[st] century. For the evaluation of the future concentrations of GHGs and aerosols in the atmosphere and their influence on the expected climate are used global climate models (GCMs). These models simulate the physical, chemical and biological processes and interactions of the system: atmosphere-oceans-terrestrial surface. The global climate models calculate the frameworks of the future climate on the base of measurements and potential future emissions of GHGs and aerosols in the atmosphere. Therefore, the climate models use as admission information the warming already observed, as well as the expected warming as a result from the registered emissions of the relevant GHGs and aerosols. Despite this, we should talk about climate scenarios but not for climate prognosis because the assumptions connected with the future climate conditions are based on the emission scenarios for GHGs and aerosols in the atmosphere.

There are over 20 centers in the world, which are dealing with modeling of the global and regional climate. Such are the Max Plank institute (Germany), Hadley Center for Climate Prediction and Research (Great Britain), Canadian Center for Climate modeling and analyses, the Australian CSIRO model center, Geophysical Fluids Dynamics Laboratory (USA) and many others. One of the main problems using the simulated climate scenarios from global climate models is connected with the so called „regionalization" or „scaling" to higher spatial resolution. There are several methods for scaling the climate scenarios, which are in four main groups: usage of the values from the closest point of the grid-network of the global climate models; interpolation of the values from 4 neighbor points of the grid-network of the global climate models; scaling by statistical models; regionalization by including additional simulations of the regional climate models. The first method is the most inaccurate and the others are characterized with positive and negative sides

GIS software can be used (ArcGis 9,2, Arc View, 3.3, Diva Surfer) for storage, interpolation and visualization of the climate scenarios for the chosen regions.

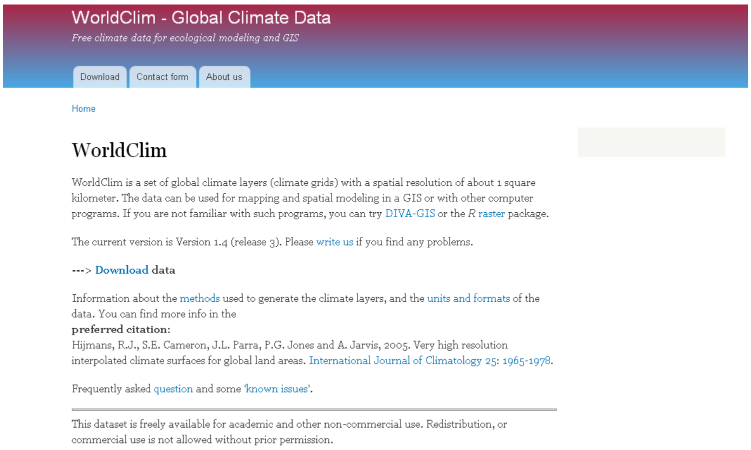
Step by step:

1. Establishment of recent climate dataset;

2. Development of climate change scenarios, and

3. Vulnerability assessment of forest ecosystems under climate change by applying the de Marton index as well as the Holdridge classification.

In case observed data are not available: during the workshop in Ljubljana the participants agreed on the opportunity to use the WorldClim dataset : http://www.worldclim.org/node/1


WorldClim - Global Climate Data
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WorldClim

WorldClim is a set of global climate layers (climate grids) with a spatial resolution of about 1 square kilometer. The data can be used for mapping and spatial modeling in a GIS or with other computer programs. If you are not familiar with such programs, you can try DIVA-GIS or the *R* raster package.

The current version is Version 1.4 (release 3). Please write us if you find any problems.

---> **Download data**

Information about the methods used to generate the climate layers, and the units and formats of the data. You can find more info in the
preferred citation:
Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978.

Frequently asked question and some 'known issues'.

This dataset is freely available for academic and other non-commercial use. Redistribution, or commercial use is not allowed without prior permission.

WorldClim

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Information about the methods used to generate the climate layers, and the units and formats of the data. You can find more info in the preferred citation: *Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978*.

This data set is freely available for academic and other non-commercial use. Redistribution, or commercial use is not allowed without prior permission. One can download climate data for:

- Current conditions (interpolations of observed data, representative of 1950-2000)
- Future conditions: downscaled global climate model (GCM) data from CMIP5 (IPPC Fifth Assessment)
- Past conditions (downscaled global climate model output)

DATA FOR CURRENT CONDITIONS (~1950-2000)

If you need the highest resolution (30 arc-seconds (~1 km)) then you can **download by tile**.

If you want global grids, choose the generic or the ESRI format and the resolution and variables you want.

See the Methods page for more info on how these data were generated, and this page for info on details about the data (such as units).

Generic grids
These grids (raster data) can be imported into most GIS applications.
30 seconds resolution Min. Temperature - Max. Temperature - Mean Temperature - Precipitation - Bioclim 1-9 & 10-18 -Altitude
2.5 arc-minutes resolution Min. Temperature - Max. Temperature - Mean Temperature - Precipitation - Bioclim - Altitude
5 arc-minutes resolution Min. Temperature - Max. Temperature -Mean Temperature - Precipitation - Bioclim - Altitude
10 arc-minutes Min. Temperature - Max. Temperature -Mean Temperature -Precipitation - Bioclim - Altitude
ESRI grids
These grids can be used in ArcMap, ArcInfo ("workstation", with the GRID module) and ArcView (with the Spatial Analyst extension).
30 arc-seconds (~1 km) Min. Temperature - Max. Temperature - Mean Temperature - Precipitation - Bioclim - Altitude
2.5 arc-minutes Min. Temperature -Max. Temperature - Mean Temperature -Precipitation - Bioclim - Altitude
5 arc-minutes Min. Temperature - Max. Temperature -Mean Temperature - Precipitation - Bioclim - Altitude

10 arc-minutes Min. Temperature -Max. Temperature -Mean Temperature -Precipitation - Bioclim - Altitude

4. Development of climate change scenarios

The highest spatial resolution (less than 1 km) will be applied.

Downscaled IPPC5 (CMIP5) data

The data available here are climate projections from global climate models (GCMs) for four representative concentration pathways (RCPs). These are the most recent GCM climate projections that are used in the Fifth Assessment IPCC report. The GCM output was downscaled and calibrated (bias corrected) using WorldClim 1.4 as baseline 'current' climate. The data are available at different spatial resolutions (expressed as minutes or seconds of a degree of longitude and latitude): *10 minutes, 5 minutes, 2.5 minutes, 30 seconds* (*these are going to be used in the project*). The variables included are monthly minimum and maximum temperature, precipitation, and 'bioclimatic' variables.

CMIP5 30-seconds

Downscaled IPPC5 (CMIP5) data at 30 seconds resolution

This page has the data at 30-seconds (of a longitude/latitude degree) spatial resolution (this is about 900 m at the equator). Other spatial resolutions are available.

The data available here are climate projections from GCMs that were downscaled and calibrated (bias corrected) using WorldClim 1.4 as baseline 'current' climate. The file format is GeoTIFF.

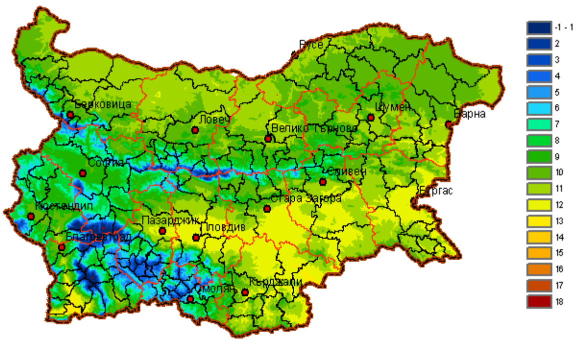
Greenhouse gas scenarios: four representative concentration pathways (RCPs)
Time periods: 2050 (average for 2041-2060) and 2070 (average for 2061-2080)
Variables:
tn - monthly average minimum temperature (degrees C * 10)
tx - monthly average maximum temperature (degrees C * 10)
pr - monthly total precipitation (mm)
bc - 'bioclimatic' variables

It is recommended to use the HadGEM2-AO (HD) climate change scenarios for the 2050s and 2070s by applying the 4 path trajectories (see above). The 2100 should be dropped out of the project study because:

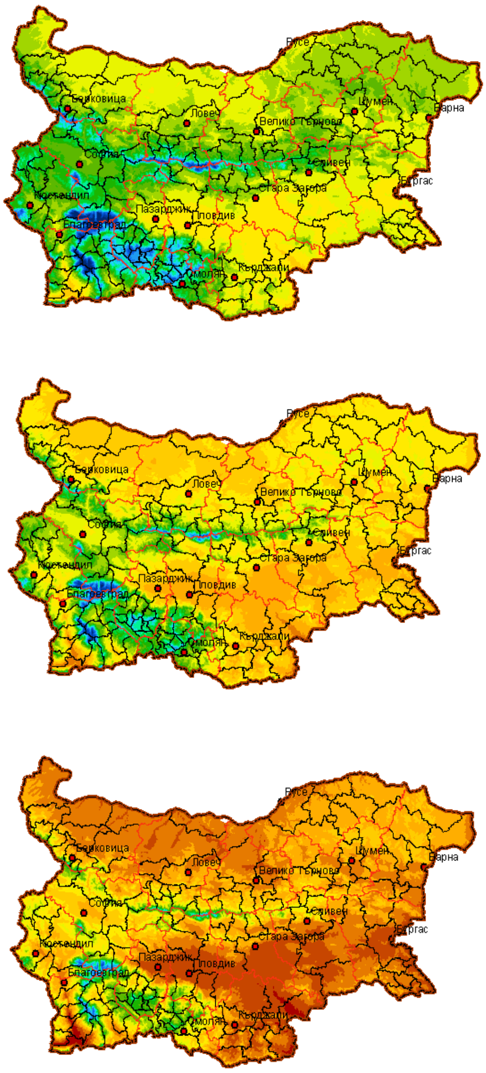
- is far away from the recent time;
- the dataset is already developed for the 2070s;
- the dataset is already with high spatial resolution (less than 1 km);
- there is no sense to develop another time period i.e. 2100 instead of 2070s as it is time and costs consuming.

5. Vulnerability assessment of forest ecosystems under climate change by applying the De Marton index and the Holdridge classification

Example for Bulgaria with different climate change scenarios (older ones) - to be implemented in a similar way by all project partners in this project (Fig. 1.2 and Fig. 1.3).



a

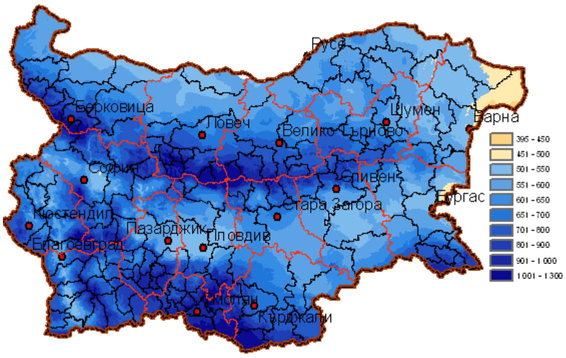


b

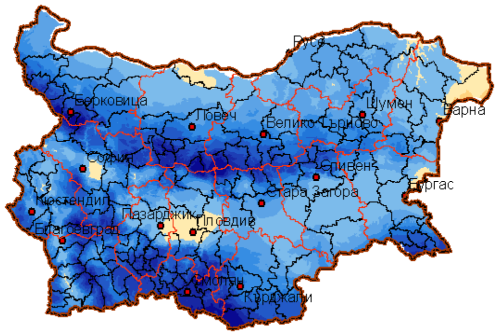
c

d

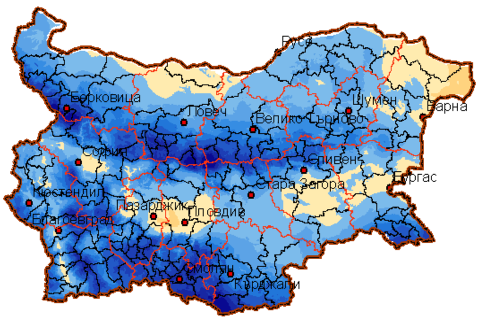
Fig. 1.2. Mean annual temperature: a – 1961-1990, and pessimistic climate scenarios – b (2020), c (2050) and d (2080)



a



b



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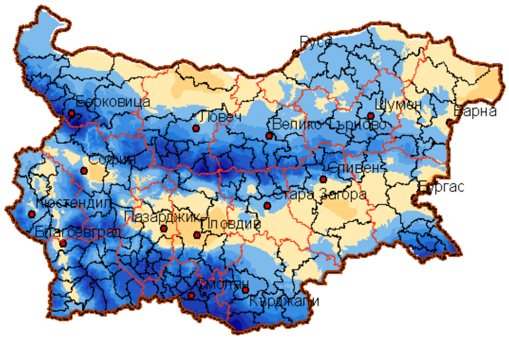

d

Fig. 1.3. Mean annual precipitation: a – 1961-1990, and pessimistic climate scenarios – b (2020), c (2050) and d (2080)

The differences in the geographical location, altitude, distance to water basins and others are determining for the vast diversity of characteristics of the climate elements for each point from the forest map of Bulgaria. The common regularity regarding this can be defined as such: with the decreasing of the altitude and in direction North-South decreases the quantity of annual precipitation and the temperature of the ground air increases. The global climate changes sharpen even more these differences and in particular cases they can lead to lethal end the forest ecosystems on vast areas. As at the beginning of the present development were outlined the problems of the forestry sector in the conditions of present climate and after that the possible trend of the climate changes in 2050 and 2070 in different scenarios, it is very important for the practice to be outlined the different zones in the Bulgarian forest map, in which the forest ecosystems will be more or less vulnerable to climate changes. This is of great importance for the establishment of differentiation system of measures for the adaption of the forests and for formulation of the main tasks for the management of the forest ecosystems in each forestry unit in terms of climate changes.

Vulnerability zones of the forest ecosystems related to water management in terms of climate changes

In the conditions of climate changes in 21st century, the different parts of Europe will be subject to different changes of the main climate elements as intensity. Even small country as Bulgaria, depending on the altitude and other physical-geographic parameters the climate changes have specifics which have influence on the water regime of the forest tree vegetation. From the conducted review of the forest hydrology literature we see that in conditions of "present climate" (the climate in the period 1961-1990) on lower altitude in the country the forests have smaller quantity of precipitation, and the temperature is increasing, which in particular years leads to water stress. This vulnerability of the forest ecosystems water balance exists also now. It will increase more as we expect changes in the next years.

Existing knowledge for the vulnerability zones in the forest ecosystems in terms of climate changes

The health condition of the forest vegetation is analyzed. There is a long dry period from 1982 to 1994; the air pollution; the introduction of coniferous species outside their areal and others. Research on the evaluation of vulnerability of the forest vegetation to future change of the climate in Bulgaria in case of doubling the CO_2, in the atmosphere is conducted. Different climate scenarios are set. Developed are scenarios based on outputs from global circulation models (GSM), as well as the so called increment scenarios for Bulgaria for the XXIst century. The aim of these models is not to predict but to outline the possible ecological changes and measures, which should be taken to mitigate the danger from them. It is used the model for life classification on Earth (1967) for specifying the vulnerability of the forest vegetation, caused by elm changes. Two climate variables are used from 20 meteorological stations on different altitude country - average monthly air temperature and annual sum of precipitation, which define the recent and future life zones. Evaluation on the life zones particularly for the forest tree vegetation is done - De Marton index, which gives quantitative explanation on the critical conditions of the climate and their suitability for the forest vegetation. The tendency shifting of the mesophyte and hydrophyte species with typical xeromorphic species resistant to a warm climate. The biological diversity is significantly reduced, the productivity decreases, the threx pests, diseases and fires increases. As there is no opportunity of giving precise prognosis for the future climate changes, the used climate scenarios support the development of measures for mitigation vulnerability of the forest vegetation to climate changes.

In Bulgaria two vulnerability zones is provisionally divided: Lower forest vegetation zone (from 0 m a.s.l. to 800 m a.s.l.) and forests in the upper part of the country (above 800 m a.s.l.).

In the Lower forest vegetation zone even now in some particular years the forest ecosystem are under serious water stress. This is the reason for drying of big part of the coniferous monocultures. In the future, taking into account the climate scenarios, the drying process will become more intensive and will reach higher altitude. For forests in the higher parts of the country the moisture conditions are significantly better. Here are the forests with highest product. Depending on the two vulnerability zones are suggested measures for the adaption of the forest future climate changes.

The outlined vulnerability zones of the forest ecosystems regarding climate parameters and particular regarding the moisture ensuring are very large scaled and do not give information for many transition situations regarding mostly the altitude. More detailed zoning of the country on these indices are necessary to be prepared well founded and appropriate with the local conditions.

Methodology for defining the vulnerability zones of the forest ecosystems

The quantitative side of the climate changes can be explained with climate indices, which give in synthetic way the scale of variables. Such is for example the De Marton dryness index, which calculates as correlation of the main climate elements - precipitation and temperature:

$$J = P/(T+10) \tag{1.1}$$

where: P and T are the annual precipitation and air temperature.

For evaluation of the suitability of a certain climate to satisfy the necessities of the forest vegetation is used the following scale:

- in index under 20 comes degradation of the forest tree vegetation due to climatic reasons,
  because of lack of moisture;
- in index from 21 to 30 exists lasting difficulties for growth;
- in index from 31 to 40 exist only temporary growth difficulties;
- in index above 40 we enter the optimal climate conditions, when the forest vegetation is in climax formation. In our conditions this optimum reaches value of 70;
- in values above 71 starts again worsening of the climate conditions, this time because of warmth lack.

The above thresholds to be evaluated by the other project countries (beyond the Bulgarian team).

The precipitations in Bulgaria are from 550 mm to 600 mm in the lowest parts and up to 1000-1100 mm the highest part of the country. The specifics of the precipitation distribution are a result from the circulation conditions over the territory of Bulgaria, which are significantly influenced by the orography. Typical for the climate in Bulgaria are the not sufficient quantities of precipitation, which is precondition for regular drying.

When the proportion between radiation balance and annual precipitation (expressed with energy, cal) is equal or close to 1, between the warmth and moisture, participating in the natural processes of the geographic environment have quantitative commensurability, namely the quantity of precipitation is as much as can be vaporized for the ground surface under the relevant warmth conditions. One of the simplest but effective approaches for connecting the vegetation structures to climate changes is the classification climate-vegetation cover. Accepting the postulate that the wide spread vegetation structures are in balance with the present climate conditions, the distribution of the vegetation species can be connected with the biologically important climate characteristics. The main approach for evaluation of the potential influence of the climate change on the forest ecosystems in this development is based on the Holdridge model for classification of the life zones. In 1949 Holdridge itself developed the method for classification of the system climate-vegetation coverage. This methodology ensures the values, connected with the vegetation coverage, representing the climatic characteristics in local, regional and global scale. The Holdridge model connects the spatial distribution of the present vegetation to the factors of the climate system. This model is appropriate for studying the wide distributed structure of the vegetation according the climate factors and can be used for evaluation of the climate change on the capability of one region or another to maintain the development of different forest types. The Holdridge model is climatic classification scheme which connects the distribution of the main ecosystem complexes to the climate indexes as bio temperature, annual precipitation and the relation between the potential evapotranspiration to the precipitation (Fig. 1.4).

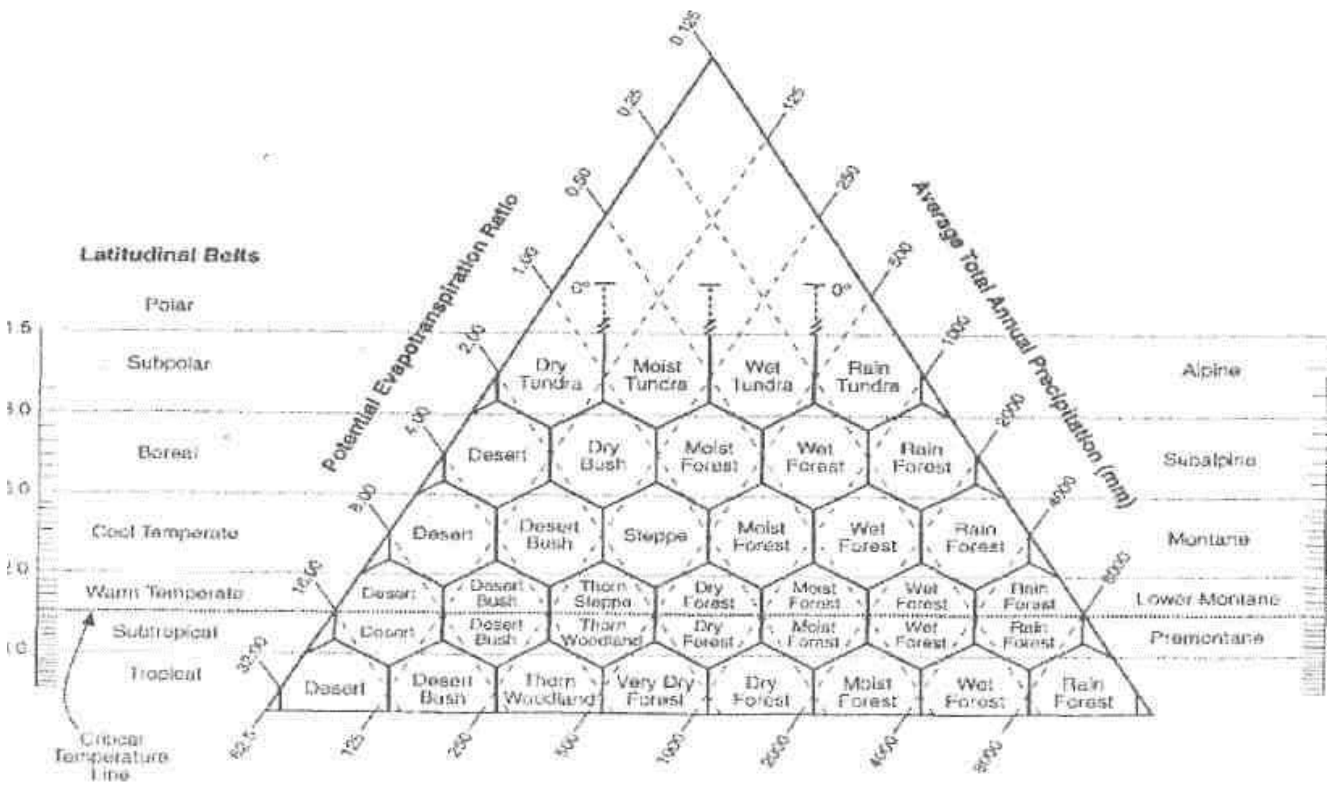

Fig. 1.4. Holdridge diagrame

One additional side of Holdridge is that the classification is based on the appearance of the phenomenon "killing" frost. This is the critical temperature which divides the hexagons 12°C and 24°C to "warm" temperature and subtropical zone. The life zones are explained with series of hexagons in one triangle coordination system. The two climatic elements - bio temperature and annual precipitation - modify the vegetation classification. The bio temperature in the particular case is the temperature sum above 0°C during one calendar year. The entire Holdridge classification includes 39 life zones (Table 1.1).

Table 1.1. Description of the life zones by Holdridge classification

Index	Description	Index	Description
1	Ice		
2	Polar desert	21	Warm temperate dry forest
3	Subpolar dry tundra	22	Warm temperate moist forest
4	Subpolar moist tundra	23	Warm temperate wet forest
5	Subpolar wet tundra	24	Warm temperate rain forest
6	Subpolar rain tundra	25	Subtropical desert
7	Boreal tundrt	26	Subtropical desert scrub
8	Boreal dry scrub	27	Subtropical thorn woodland
9	Boreal moist forest	28	Subtropical dry forest
10	Boreal wet forest	29	Subtropical moist forest
11	Boreal rain forest	30	Subtropical wet forest
12	Cool temperate desert	31	Subtropical rain forest
13	Cool temperate desert scrub	32	Tropical desert
14	Cool temperate steppe	33	Tropical desert scrub
15	Cool temperate moist forest	34	Tropical thorn woodland
16	Cool temperate wet forest	35	Tropical very dry forest
17	Cool temperate rain forest	36	Tropical dry forest
18	Warm temperatedesert	37	Tropical moist forest
19	Warm temperate desert scrub	38	Tropical wet forest
20	Warm temperate thorn scrub	39	Tropical rain forest

Vulnerability zones of the forest ecosystems towards climate changes

The vulnerability zones of the forest ecosystems for present climate (1961-1990) and for the years 2020, 2050 and 2080 are defined using the climate scenarios for Bulgaria for the same period, as well as using calculations of some of the complex climate indices of: De Marton and by the Holdridge life zones.

The Marton index can be easily calculated for the recent and expected climate. A software for the calculation of the Holdridge classification will be provided by the Bulgarian partner. The idea is to obtain vulnerability maps like these in Fig. 1.5 and Fig. 1.6.

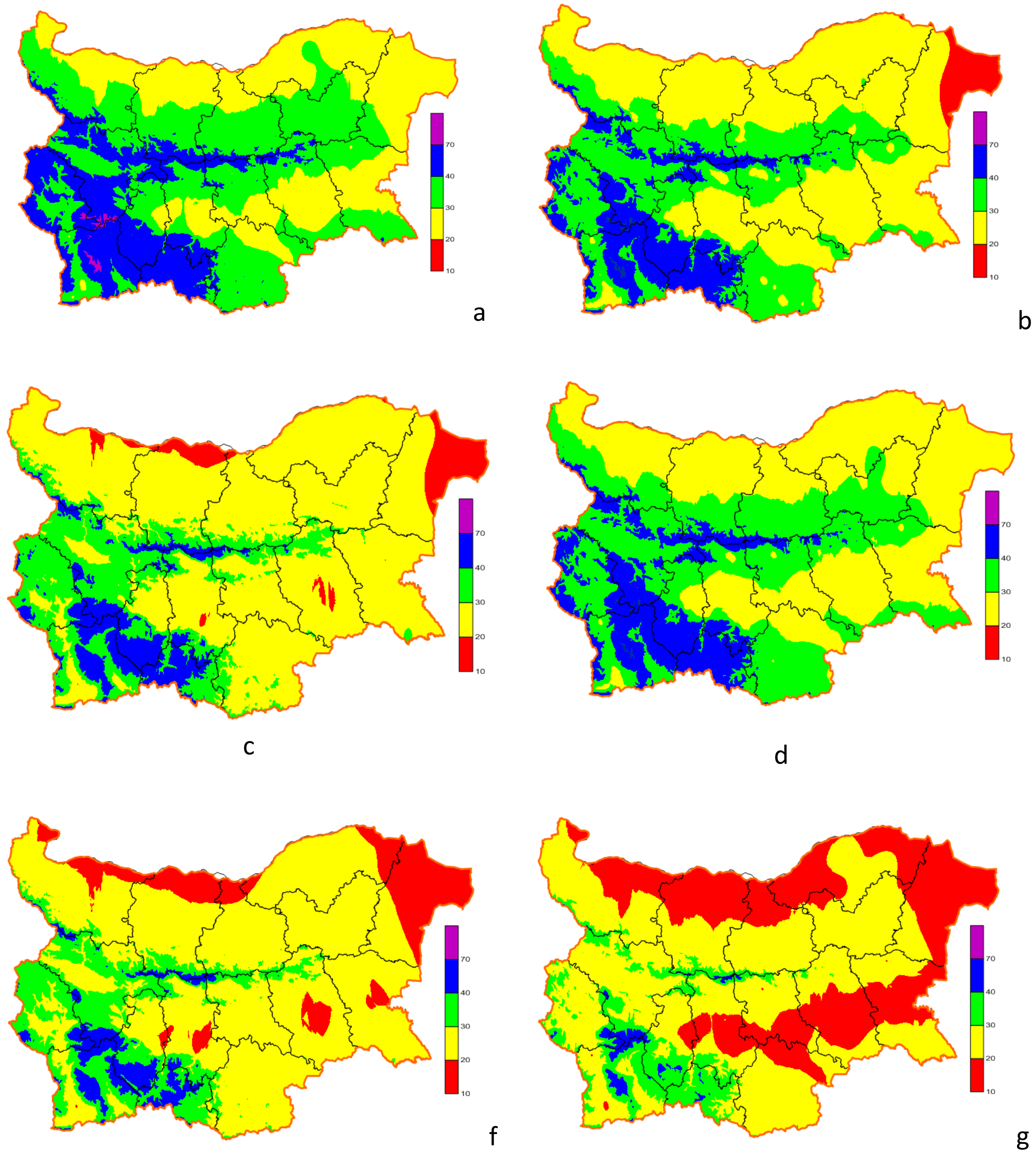

Fig. 1.5. De Marton index for present climate (1961-1990) (a), 2020 (b - realistic scenario), 2050 (c - realistic scenario), 2080 (d - optimistic, f- realistic and g - pessimistic scenarios) (< 20 - deficit in moistening (destruction of vegetation); 21 - 30 - lasting disturbances in moistening, 31-40 - disturbances in moistening for particular years, 41-70- optimal moisture conditions, > 70 - over moistening)

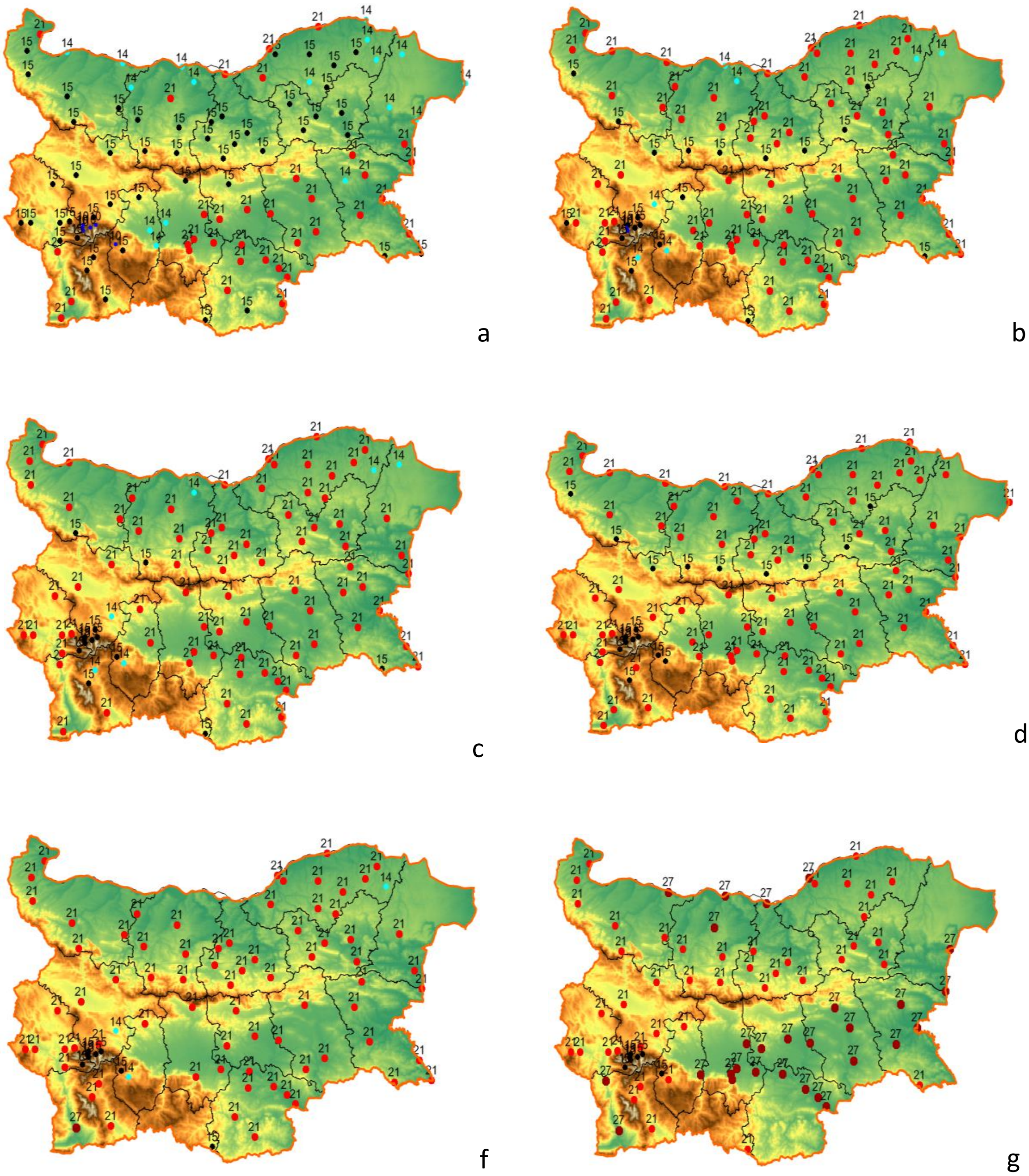

Fig. 1.6. Holdridge classification for the current climate (1961-1990) (a), 2020 (b – realistic scenario), 2050 (c – realistic scenario), 2080 (d – optimistic scenario f – realistic and pessimistic scenario) (14 – temperate cool step; 15- temperate cool fresh forest, 21-temperate warm dry forest, 27 – subtropical forest land with thorns)

2050				
GCM	**code**	**rcp26**	**rcp45**	**rcp60**
ACCESS1-0 (#)	AC		tn, tx, pr, bi	
BCC-CSM1-1	BC	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
CCSM4	CC	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
CESM1-CAM5-1-FV2	CE		tn, tx, pr, bi	
CNRM-CM5 (#)	CN	tn, tx, pr, bi	tn, tx, pr, bi	
GFDL-CM3	GF	tn, tx, pr, bi	tn, tx, pr, bi	
GFDL-ESM2G	GD	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
GISS-E2-R	GS	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
HadGEM2-AO	HD	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
HadGEM2-CC	HG		tn, tx, pr, bi	
HadGEM2-ES	HE	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
INMCM4	IN		tn, tx, pr, bi	
IPSL-CM5A-LR	IP	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
MIROC-ESM-CHEM (#)	MI	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
MIROC-ESM (#)	MR	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
MIROC5 (#)	MC	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
MPI-ESM-LR	MP	tn, tx, pr, bi	tn, tx, pr, bi	
MRI-CGCM3	MG	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
NorESM1-M	NO	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
2070				
GCM	**code**	**rcp26**	**rcp45**	**rcp60**
ACCESS1-0 (#)	AC		tn, tx, pr, bi	
BCC-CSM1-1	BC	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
CCSM4	CC	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
CESM1-CAM5-1-FV2	CE		tn, tx, pr, bi	
CNRM-CM5 (#)	CN	tn, tx, pr, bi	tn, tx, pr, bi	
GFDL-CM3	GF	tn, tx, pr, bi	tn, tx, pr, bi	
GFDL-ESM2G	GD	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
GISS-E2-R	GS	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
HadGEM2-AO	HD	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
HadGEM2-CC	HG		tn, tx, pr, bi	
HadGEM2-ES	HE	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
INMCM4	IN		tn, tx, pr, bi	
IPSL-CM5A-LR	IP	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
MIROC-ESM-CHEM (#)	MI	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
MIROC-ESM (#)	MR	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
MIROC5 (#)	MC	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
MPI-ESM-LR	MP	tn, tx, pr, bi	tn, tx, pr, bi	
MRI-CGCM3	MG	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi
NorESM1-M	NO	tn, tx, pr, bi	tn, tx, pr, bi	tn, tx, pr, bi

MODELS OF CLIMATE CHANGE ON FORESTS IN SLOVENIA, LITHUANIA AND UKRAINE

1. Slovenia

In the framework of several research projects a number of empirical models of climate change impacts on Slovenian forests were generated and model-based maps of forest vulnerability zones were drawn.

The most recent modeling iteration has been financially supported by research project “Adaptation of forest management to climate changes in relation to expected changes of forest traits and forest spatial changes, V4-0494”, funded by the Ministry of Agriculture, Forestry and Food and by the Slovenian Research Agency, and by the research programme P4-0107 funded by the Slovenian Research Agency

We studied the potential forest tree species composition and the forest type under three climate change scenarios, which would affect the ecological and economic sustainability of the forests. The goal was to study the potential decline of the main tree species and forest vegetation types in Slovenia due to the effects of climate change. Multi-target quantitative models of growing stock and vegetation have been calibrated with machine-learning methods from empirical data based on previous climate data, relief and soil data. Using the models and the existing predictions of the likely future climate warming, the simulations showed changes of forest site conditions, and consequently potential tree species decline and changes of spatial pattern of vegetation types in Slovenia until the year 2100 under three climate warming scenarios (optimistic, middle, pessimistic scenario).

Model-based predictions show a significant alteration in forest tree species composition and forest vegetation in Slovenia even under the optimistic scenario. At the end of the century, the abundance of the three structurally most important species (Fagus sylvatica, Picea abies and Abies alba) will potentially be reduced by 54% to 97%, depending on scenario and species. The suitable areas for these species will be reduced to the mountainous parts. Under the pessimistic scenario, an almost total decline of Abies alba and Picea abies is predicted, whereas suitable conditions for Fagus sylvatica will only remain available in the high mountain belt. Under different climate warming scenarios, the share of dominant beech vegetation types is likely to be reduced, and the area of warmth-tolerant forests and tree species, among them invasive species of Robinia pseudoacacia will increase significantly.

1.2. Introduction

The results of climate research suggest that the risks caused by weather extremes may increase considerably in future (IPCC 2001, 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). The Mediterranean region and Alps could be among the most affected regions by climate change (IPCC 2007).

Forest ecosystems in Europe are very likely to be strongly influenced by climate change and other global changes (e.g. Shaver et al. 2000, Blennow and Sallnäs 2002, Askeev et al. 2005, Kellomäki and Leinonen 2005, Maracchi et al. 2005, IPCC 2007). 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, 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).

The aim of this study is to simulate the future tree species and forest vegetation distribution in Slovenia driven by different climate warming scenarios, in order to enable a timely adjustment of forest management and forest sylvicultural measures.

1.3. Methods

For the 16 most frequent forest tree species (each exceeding 0.5 % of total forest regression tree technique called random forests (Breiman 2001). The target variables' values of 16077 quadrants were extracted from raster maps of current growing stock for each species and vegetation type, which were aggregated from the 2008 National forest stand map in scale 1:5000 (Slovenian Forest Service 2008).

The simulation of forest vegetation type is based on the forest-plant community system by Košir et al. (1974, 2003), described on more than 70,000 forest compartments (Slovenian Forest Service 2008). Based on the similarity of site characteristics with a special emphasis on climatic factors, the potential-forest-community types have been agregated together in 13 vegetation types.

The explanatory variables for model training were based on raster maps of the following factors: the maps of average monthly and yearly precipitation R, temperature T and evapotranspiration E for the period 1970 – 2000 (Environmental Agency of Republic of Slovenia 2005, 2006a, 2006b), the map of FAO soil types (Centre for Pedology and Environmental Protection 1999), and the maps of the average relief elevation, average relief slope and relief diversity derived from a digital elevation model with resolution of 100 m (Surveying and Mapping Authority of the Republic of Slovenia 2006).

The model was validated by a 10-fold cross-validation. The future (year 2100) values for each quadrant were then predicted by feeding into the model the predicted year 2100 values of the climatic factors (Bergant 2007), according to three scenarios, which differ in combining upper or lower bounds or median values of climate predictions.

Using the model and the existing predictions of the likely future climate (Bergant 2007), we predicted the shift of tree species and forest vegetation distribution in Slovenia for the year 2100 under three climatic scenarios: the middle scenario (median predicted temperature T, median predicted precipitation R, median predicted evapotranspiration E), the pessimistic scenario (max T, min R, max E), and the optimistic scenario (min T, max R, min E). Since the empirical model is only valid within the present forest area, it cannot predict change of the forest area due to climate warming. Therefore, our predictions of vegetation change were only made within the present confines of the forests.

Finally, a compound measure of change was computed based on Euclidean distance between the current (modelled) forest tree species composition and the forecasted potential composition. The greater the Euclidean distance, the greater vulnerability of forests under the simulated climate change scenarios.

1.4. Results

Taking into consideration the future climate changes (defined by three different climate scenarios: the middle scenario, the pessimistic scenario and the optimistic scenario), the simulation of the future tree species distribution and potential forest vegetation predicts significant changes in Slovenia. The significant decline of growing stock and area of three dominant tree species in Slovenia, Picea abies, Fagus sylvatica, and Abies alba has been predicted (Fig. 2.1 and Fig. 2.2, Table 2.1).

Table 2.1. The current and predicted average growing stocks of dominant tree species, within each species' area of distribution in Slovenia, as absolute values (a) and as relative changes, compared to the modelled absolute values of the year 2000 (r).

	Growing stock (m^3/ha), Relative change of growing stock						
	Year 2000	Year 2100, middle scenario		Year 2100, optimistic scenario		Year 2100, pessimistic scenario	
Tree species	(a)	(a)	(r)	(a)	(r)	(a)	(r)
Picea abies	149.6	15.1	-90%	49.9	-67%	5.2	-97%
Abies alba	37.6	3.4	-91%	14.1	-63%	1.0	-97%
Fagus sylvatica	139.1	32.8	-76%	64.3	-54%	24.8	-82%

At the end of the century, the abundance of these three structurally most important species will significantly be reduced. In the present area of distribution, the growing stock of Picea abies might be reduced by 67% to 97%. The decline of Fagus sylvatica growing stock by 54% to 82% and of Abies alba by 63% to 97%, is projected (Table 2.1). The suitable areas for these species will be reduced to the mountainous parts of Slovenia. Under the pessimistic scenario, an almost total decline of Abies alba and Picea abies is predicted, whereas suitable conditions for Fagus sylvatica will only remain available in the high mountain belt.

The simulation showed that under the middle scenario warmer conditions the growing stock decline of more than 50% was predicted for 7 out of 16 tree species, among those a decline of more than 75% was predicted for Abies alba, Picea abies, Pinus sylvestris, Larix decidua, Acer pseudoplatanus and Fagus sylvatica. On the other hand, the increase of some thermophiluous, warmth-tolerant tree species is forecasted. Most significant potential increase (by 97% to 139%, depending on the scenario) is predicted for Robinia pseudacacia, followed by Ostrya carpinifolia (20% to 103%) and Pinus nigra (34% to 75%).

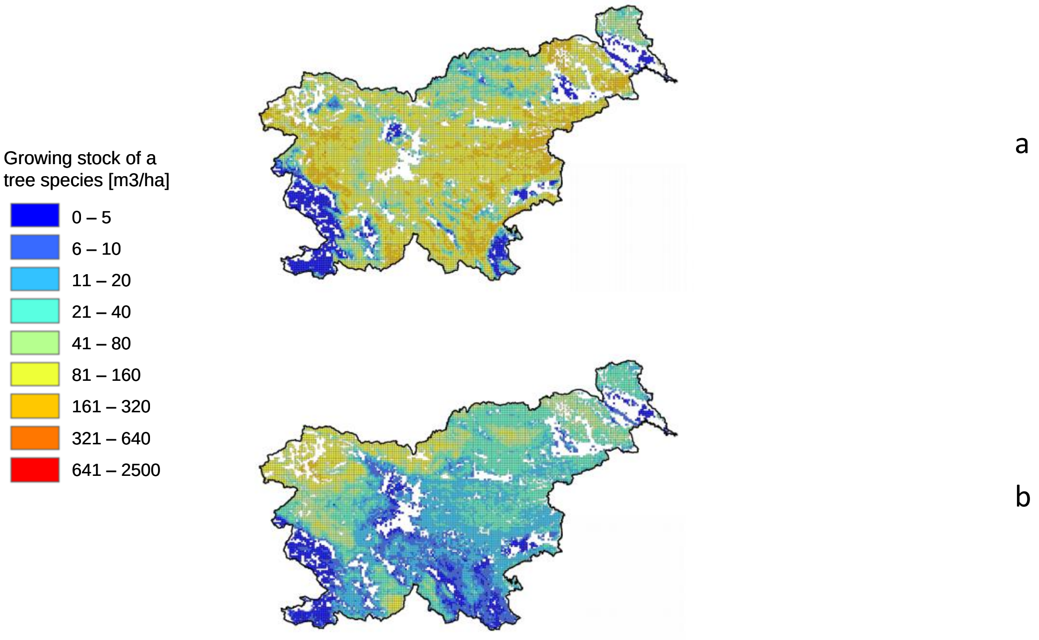

Fig. 2.1: Spatial prediction of growing stock of Fagus sylvatica in Slovenia – a comparison of the present-day distribution (a) and the predicted year 2100 potential distribution, according to the middle scenario (b).

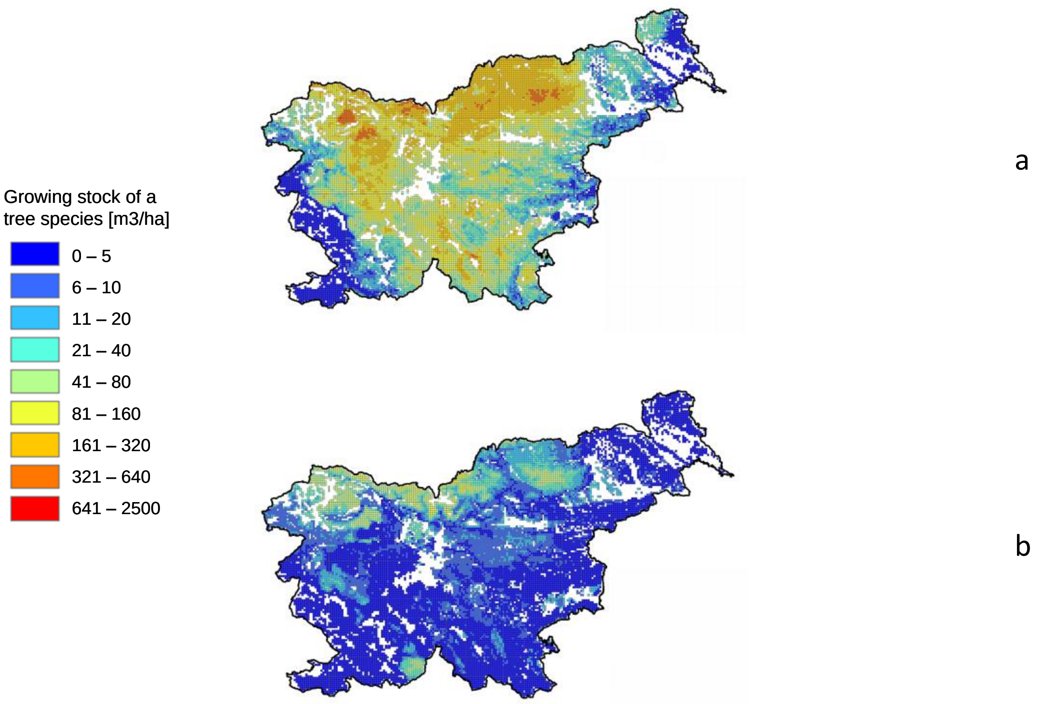

Fig. 2.2. Spatial prediction of growing stock of Picea abies in Slovenia – a comparison of the present-day distribution (a) and the predicted year 2100 potential distribution, according to the middle scenario (b).

The mesic forest vegetation, prevails in Slovenia may be adversely affected by changing environmental conditions. The decrease of the share and distribution of currently prevailing Acidophilic Fagus sylvatica forests (Fig. 2.3) and Submontane Fagus sylvatica forests could be expected. Till the year 2100, the constant decreasing of (Alti-) montane Fagus sylvatica forest in the (Pre-)Dinaric region, among which Dinaric fir-beech forests (Abieti-Fagetum dinaricum, sin. Omphalodo-Fagetum) prevail, has been forecasted.

On the contrary, the warmer climate predicted by all three future scenarios will favour drought-tolerant forest species and vegetation types. The changed environmental and forest site conditions will be more suitable for growing of different thermophile forests, which are mostly dominated by different drought-tolerant tree species, like Ostrya carpinifolia, Fraxinus ornus, Sorbus aria, Quercus pubescens, Q. cerris and Q. petraea, and also some coniferous species like Pinus sylvestris and P. nigra. Even different Mediterranean evergreen forests and maquis shrublands with dominant Quercus ilex, Q. coccifera, Pinus halepensis or Carpinus orientalis could possibly be distributed over extreme warm sites in Slovenia. By the end of century, the share of different thermophile vegetation might be enlarged significantly.

The compound vulnerability of the present forest tree species composition under predicted climate change is unfortunately the greatest in the areas that are ecologically especially vulnerable (alpine region and the high karts in the Dinaric mountains), where at the same time are also the largest part of economic wood production is currently taking place (Fig. 2.4).

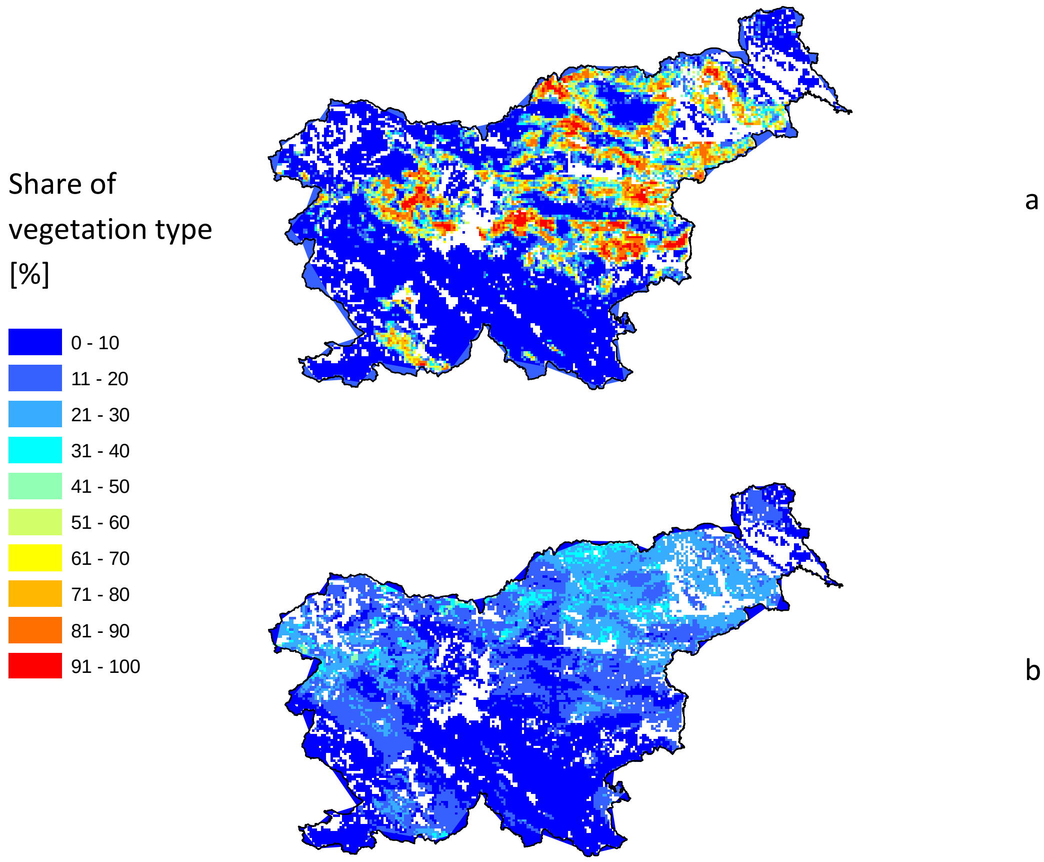

Fig. 2.3. Share of Acidophilic Fagus forests in each square kilometer in Slovenia – a comparison of the present-day distribution (a) and the predicted year 2100 potential distribution, according to the middle scenario (b).

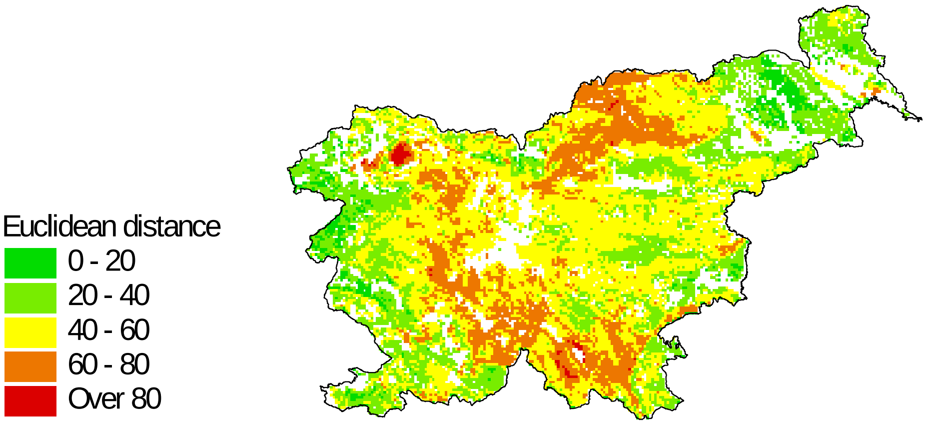

Fig. 2.4. Vulnerability of the predicted forest tree composition (year 2100, middle scenario) according to the Euclidean distance between the current (modelled) forest tree species composition and the forecasted potential composition. The greater the Euclidean distance, the greater vulnerability of forests under the simulated climate change scenario

1.5. Discussion and conclusions

We 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 our 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 an almost total decline of Picea abies and Abies alba is potentially forecasted.

Some warmth-tolerant tree species, among them invasive species of Robinia pseudoacacia will increase significantly. The share of different thermophile species and forests, which are less economically interesting and more fire-prone, will increase significantly, replacing the currently predominant species and forests. The extension of thermophile species and forests all over the country would have very dramatic consequences and would affect forest-management, forest policy, and forest protection activities. The shift from dominant semi-natural mesic forests to low density forests or woodlands is likely to happen by the end of the 21st century. The production of high-quality wood is one of the main objectives of forest management at present, but forests provide a wide range of other benefits. The future forest roles might be critically affected by redistribution and changed proportions among the forest types.

On particular sites in the centre of the current area of distribution of beech in central Europe, beech may lose its dominance and growing potential as compared to drought or flood-tolerant species (Geßler et al. 2006). Since similar impacts are also likely to occur in the studied area, forest policy and management need to take such risk into consideration. Species-rich forests with a high resilience potential will reduce the risk for forestry related to the prognosticated climate development in this region.

By the end of century, a decrease of the area of Dinaric fir-beech forests (Omphalodo-Fagetum) has been forecasted (Kutnar and Kobler 2007, 2011, 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. It seems that Dinaric fir-beech forest, which is one of the most extensive forest communities in Slovenia (Dakskobler 2008) might be the most threatened. Beside their significant forest-management role, the Dinaric fir-beech forests are among the most important timber productive forests; their ecological and nature-conservation aspects are also significant. In area of these forests, the central part of habitat of three large European beasts of prey, the brown bear, lynx, and wolf, and of many other species of Community interest (e.g. Habitat Directive 1992), and the major part of these forests has been designated as part of the Natura 2000 network. Thus, the loss of habitat of Dinaric fir-beech forests is likely to mean the potential extinction of many key species.

Our model, similarly to other empirical distribution models (Zurell et al. 2009), is relatively static and does not account for secondary effects of climate warming. Beside the relatively uncertain climate-change scenarios, a potentially changed ecological niche of existing tree species and forest vegetation types under changed climate or even the ecological niche of future forest vegetation types with other dominant tree species have not been considered. Moreover, the secondary effects of climate change (e.g. higher frequency of forest fires, land use change, and especially effects of tree diseases and harmful pests and their new appearances (Jurc and Ogris 2006, Jurc et al. 2006, Ogris et al. 2006, Piškur et al. 2011) have not been foreseen in the models.

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2. Lithuania

Outputs from the HadCM3 Global Climate Circulation Model according to scenarios A2 and B1 were used for climate change predictions in Lithuania. According to scenario A2, the annual temperature will increase by approximately 4.0°C from 2061 to 2090, while scenario B1 predicts an increase of 2.0°C. In contrast to scenario B1, scenario A2 predicts an annual increase in precipitation of 15–20 % at the end of the century. Based on the predicted climatic data for the two scenarios and climate maps by European Food Safety Authority for the EU, we created climate analogues for Lithuania for 2031–2060 and 2061–2090. These areas were overlain by the digital map of native tree species distributions in Europe, which was created from the European Forest Genetic Resources Programme database. If climate changes occur according to scenario B1, in 2031–2060, Lithuania's climate will become suitable for approximately five to six alien species. If climate changes occur according to scenario A2, at the end of the twenty-first century approximately 20 new species native to Europe will be suitable for cultivation (scenario A2). Climate change will affect the distributions of native species too.

The climate with respect to the mean annual temperature, mean February temperature, and annual amount of precipitation that is characteristic of Lithuania can be found in neighboring territories or in other parts of Europe. Currently, Latvia, Estonia, the southern part of Sweden, the Kaliningrad region of Russia, northern Poland, mountain regions of central and southern Germany, Czech Republic, and Slovakia. Nonetheless, the species composition of forests in these regions is different. In 2031–2060, according to scenario B1 (for which the predicted annual temperature will increase by 1°C without a change in precipitation), the climate of Lithuania will become similar to the present climate in the north-western and south-western regions of Germany. According to scenario A2 (in which the annual temperature will increase by 2°C), the climate will be similar to the present climate in north-western and south-western Germany, the Netherlands, and the north-eastern region of France. In 2061–2090, according to scenario B1 (for which the annual temperature will increase by 2°C), the climate in Lithuania will be similar to the present climate in Denmark, western Germany, the Netherlands, and Northern France. According to scenario A2 (for which the annual temperature will increase by 4°C and precipitation will increase by 15–20%), the climate will be similar to the climate that is currently characteristic of the western parts of Belgium and in the northern and southern territories of France. European territories that correspond to the predicted future climate of Lithuania are presented in Fig. 2.5. It is evident that the areas with predicted analogous climate differ under various climate change scenarios, and their changes in timescale have a south-west direction.

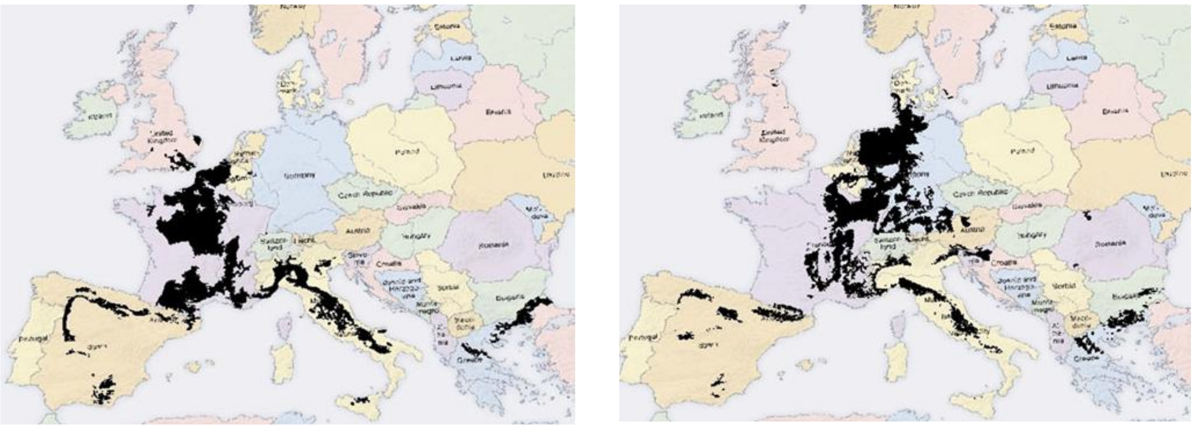

Fig. 2.5. European territories that are similar to the predicted future climate of Lithuania, according to climate change scenarios A2 (left) and B1 (right) for period 2061-2090

First of all, we must separate two definitions: potential species and potential immigrants. Potential species can be defined as species that will be suitable to grow in the corresponding climatic conditions. Potential immigrants are species that can naturally spread (in our case, due to climate change) and reach territory that is suitable for their growth.

The list of potential immigrants will not include species that are distributed in small areas, endemic species (e.g. Acer monspessulanum and A. opalus), species that have slow dispersal speeds or that remain in a natural mountain range for a long time because of their biological particularities (e.g. Abies alba, Larix decidua, and Pinus mugo), and species that have natural barriers (seas, mountains) that limit their expansion, i.e. species that grow under the northern line of the Abies alba distribution area (e.g. Pinus cembra).

The analysis of matching species distribution and climate maps shows that, even now, Lithuania's climate is suitable for the growth of some foreign species (Quercus pubescens, Abies alba, Larix decidua, Fagus sylvatica, Taxus baccata, Pinus cembra, Tilia platyphyllos, Quercus petraea, and Acer pseudoplatanus), i.e. the mapped territories with climate similar to present-day Lithuania fall into the distribution area of some species.

The results show that areas with predicted climates similar to that of present-day Lithuania, as predicted according to climate change scenarios A2 and B1, fall into the distribution range of some species. In some cases, these areas will occupy the western part of a species distribution range.

It is evident that the climate suitability of Lithuania for the growth of the chosen species depends on the climate change scenario. In general, scenario A2 is more favourable for immigrant species. If the climate changes according to scenario B1, it is probable that in 2031–2060, the climate of Lithuania will become suitable for approximately five to six alien species that will become potential immigrants—Acer campestre, A. pseudoplatanus, Fagus sylvatica, Populus nigra, and Prunus avium. In 2061–2090, these species will be joined by Sorbus domestica and Tilia platyphyllos. If climate changes according to scenario A2, at the end of the twenty-first century, Castanea sativa, Quercus pubescens, and Sorbus torminalis could expand the list of possible immigrants. Among species for which the climatic conditions of Lithuania can be suitable for growth (potential species), some European species other than Quercus petarea and Larix decidua should be added to the list presented in Table 1: Aser monspessulanum, A. opalus, Abies alba, Alnus cordata, Larix decidua, Pinus cembra, P. Halepensis, and P. nigra. Therefore, approximately 20 new species native to Europe will be suitable for cultivation in the forests of Lithuania at the end of the current century (scenario A2).

Table 2.2. Possible immigrant species to Lithuania under A2 and B1 scenarios of climate change. + Lithuania's climate suitable for species; +? likely suitable; - not suitable. (There is only a small island of Quercus petraea in the southern part of Lithuania)

Species	Scenario A2		Scenario B1	
	2031–2060	2061–2090	2031–2060	2061–2090
Acer campestre	+	+	+	+
Acer pseudoplatanus	+	+	+	+
Castanea sativa	-	+	-	-
Fagus sylvatica	+	+	+	+
Populus nigra	+	+	+	+
Prunus avium	+	+	+	+
Quercus petraea	+	+	+	+
Quercus pubescens	+?	+	-	+?
Sorbus domestica	+	+	-	+
Sorbus torminalis	+?	+	+?	+?
Tilia platyphyllos	+	+	+?	+

Table 2.3. Climatic conditions predicted for some Lithuanian native forest tree species according to A2 and B1 scenarios. Signs meaning is the same as in Table 2.2. (Species Abies alba, Larix decidua, and Pinus mugo that have a stable distribution range in a mountain area have not been assessed).

Species	Scenario A2		Scenario B1	
	2031–2060	2061–2090	2031–2060	2061–2090
Acer platanoides	+	+	+	+
Alnus glutinosa	+	+	+	+
Alnus incana	+?	-	+?	+?
Betula pendula	+	+	+	+
Betula pubescens	+	+	+	+
Fraxinus excelsior	+	+	+	+
Malus sylvestris	+	+	+	+
Picea abies	-	-	-	-
Pinus sylvestris	+	-	+	+?
Pyrus pyraster	+?	+	-	+?
Populus tremula	+	+	+	+
Quercus robur	+	+	+	+
Tilia cordata	+	+	+	+
Ulmus laevis	+	+	+	+

Climate change and native species The data predict that climate warming will also affect the distributions of native species. It is expected that there will be an increase in the proportion of deciduous tree species and that there will be some reduction in conifers, especially Norway spruce (Picea abies) and partly Scots pine (Pinus sylvestris). The analysis revealed that according to climate change scenarios A2 and B1, climatic conditions will become less suitable for conifers and more suitable for almost all deciduous species, except Alnus incana (Table 2.3).

Particularly, negative climate changes are forecasted for Picea abies. The climatic conditions according to both scenarios will become unsuitable (less suitable) at the middle of the current century. If the climate changes according to scenario A2, the climate in Lithuania partly will be not suitable for Pinus sylvestris at the end of the century. Only if the climate changes according to scenario B1 will there be some areas (eastern part of Lithuania) suitable for Pinus sylvestris. Currently, natural pine stands grow in a large area that ranges from the Alps through Europe to the north-east. The area of predicted future climate (using both scenarios A2 and B1) will remain in the distribution range of this species. The climatic conditions will only be unsuitable for Alnus incana if the climate changes according to scenario A2.

Natural barriers can be a significant obstacle for species migration and distribution (Skov and Svenning 2004; Bugmann 1999; Parmesan 2006). Therefore, species do not cover the entire suitable area for their growth. For example, during the Holocene, only five species from the list of 55 occupied 90 % of the territories suitable for their growth, and the rest of the 50 species occupied only 40 % of their potential area (Skov and Svenning 2004). On the other hand, natural barriers such as mountains and large water basins play a substantial role in species distribution (Schwartz 1991; Skov et al. 2009). The migration corridor defined for the predicted area of Lithuania restricted by the

Baltic and North Seas in the north and north-west, and large mountain areas in the south (Alps, Carpathian mountains) and south-west (Pyrenees) is quite similar, which was applied in a study in which the impact of climate change on the flora of Denmark was analysed (Skov et al. 2009).

The trend of number of dominant tree species confirms that tree migration and the colonisation of suitable habitat lag considerably behind the predicted rates of climate change (Schwartz 1991; Svenning and Skov 2004). Species that are geomorphically restricted from shifting their ranges to higher altitudes, such as mountain species, are expected to be replaced by more competitive species (Bugmann 1999; Parmesan 2006). The selection of potential immigrants to the forest of Lithuania at the end of the twenty-first century must be based on the distance between their natural range and Lithuania. Post-Pleistocene tree migrations proceeded at an average rate of 10–40 km per century, with a maximum migration rate of 200 km per century for Picea glauca (Schwartz 1991). The predictions of northward shifts of the range of climate suitable for individual species during the twenty-first century vary from 100 to 500 km (Melillo et al. 1990; Davis and Zabinski 1991; Hansen et al. 2001). Therefore, trees that have a distribution borderline at a distance greater than 500 km do not have a high chance of reaching Lithuania. In this respect, there is some, but presumably relatively high probability that Acer campestre, A. pseudoplatanus, Fagus sylvatica, Populus nigra, and Prunus avium will become immigrants to Lithuanian forests. We can add Quercus petraea to this list because there is a small island outside of its natural range in the southern part of Lithuania (Navasaitis et al. 2003), and we can also add Larix decidua, which has spread in some parts of Poland. According to the climate change scenarios A2 and B1, climatic conditions in Lithuania will become less suitable for Norway spruce (Picea abies) and partly as Scots pine (Pinus sylvestris). In species composition, the larger proportion may compose the native nemoral species (Acer platanoides, Fraxinus excelsior, Quercus robur, Tilia cordata, and Ulmus spp.) and potential immigrants such as Acer campestre, A. pseudoplatanus, Fagus sylvatica, Populus nigra, and Prunus avium.

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3. Ukraine

3.1. Introduction

In Ukraine there are five natural climatic zones:

1) Temperate forest zone (Polissya),
2) Temperate forest-steppe zone,
3) Temperate steppe zone,
4) Zone of subtropical dry forests (The south coast of Crimea),
5) Vertical zoning in the Carpathians and Crimean mountains.

Ukraine has a mostly temperate continental climate, although the southern Crimean coast has a humid subtropical climate [0]. Precipitations are distributed disproportionately; highest in the west and north and lowest in the east and southeast. Western Ukraine receives around 1200 -1600 millimeters (Carpathians) of precipitation annually, while on south-east just around 300-400 millimeters. Winters vary from cool along the Black Sea (average temperature of January +2…+4°C) to cold farther inland (up to –7…–8°C on the north-east). Average annual temperatures range from +5-+7°C in the north, to +11°C +13°C in the south. Average temperature of July varies from+17…+19°C on the north-west up to +22…+2 °C on south-east. Increasing of continentally index is observed from west to east.

For the plain part of Ukraine and Carpathians the summer maximum of precipitations is specific, and for Crimean mountains – winter maximum. On the plain part of Ukraine annual precipitation also varies from west to east: (from 700 mm on the west of Polissya and Forest steppe to 300-350 mm in southern regions. The maximum precipitations are in Carpathian mountains (maximum up to 1500 mm), and in Crimean mountains over 1000 mm annually.

The warming trend in Ukraine during the last 100 years [1,0 2, 3]:

(1) the warming trend over the country was similar to the global trend (0.4–0.6^{o}C), more intensive in winter (1.2^{o}C) and spring (0.8 ^{o}C); the summer warming was 0.2-0.3 ^{o}C;

(2) the temperature trend had a cycling character over the period with the highest warming during the recent period (+0.4 ^{o}C/decade for the period 1979–2003);

(3) for a major part of the territory, the precipitation trends were rather weak and varied in different regions; overall, the annual amount of precipitation remained stable or slightly decreased;

(4) instability of weather increased, and periods of long droughts, heat waves and intensive precipitation became more frequent and destructive.

Variability of climate seems to be the most unfavorable feature of recent and on-going climate change. During the last two centuries, frequency of droughts increased on average by 2–3 times. There are 187 meteorological stations in Ukraine (Fig. 2.6).

Fig. 2.6. Grid of 187 meteorological stations in Ukraine

3.2. Pilot area

The pilot area for project (land area, 1000 ha -8193; forest area, 1000 ha-1095) is located in east part of Ukraine and included 3 regions - Sumy, Kharkiv and Lugansk). The territory is rather heterogeneous by natural climatic conditions, forest cover and tree species composition. On this territory there are three natural climatic zones: Forest zone (northern part of Sumy region), Forest steppe zone (the main part of Sumy region and north-west part of Kharkiv region) and Steppe zone (zone of ravine forests) (part of Kharkiv region and all territory of Lugansk region). Climate is temperate continental, but in Lugansk region it is dryer, with warmer and dryer summer, and cooler winter.

The forest cover in Sumy region is 17,4 %, and in Lugansk is 10,7 %. The main forest forming species are *Quercus robur* and *Pinus sylvestris*. The big part of forest stands (especially pine) are artificial. According to forest inventory data pine stands in Lugansk region cover over 75% of all forest areas, in Kharkiv - 53 %, and in Sumy about 40 %.

3.3. Method

Climate classification by forest site types (prof. Vorobjov's model , 1960)

Vorobjov classification relates climate conditions with type of forest sites - type of forest that grows at a plain position on a primary relief with undisturbed soils indicates forest type of the climate and such type of forest called as zonal type of forest. There are many other types of forest in this climate, but their variability depends of relief, soil and water conditions. For example, zonal type of forest in the Ukrainian steppe zone is dry and fertility site condition (dry grud).

Two climatic indices are used to describe forest type of climate. These are heat index T and humidity index W (Table 1 and 2). Heat index is year sum of mean monthly temperatures for months with positive mean monthly temperature. Vorobjov climate humidity index is:

$$W = R/T - 0{,}0286*T \qquad (2.1)$$

where R is sum of precipitation values for months with positive mean monthly temperature.

Scales of variables W and T are forming a grid of Vorobjov climates. Grades on T scale are equal to 20^0C and grades on W scale are equal to 1,4. Each cell has own code, that formed of digit corresponding to humidity index on W scale, and letter corresponding to heat index on T scale (e.g. 1d, 2e).

Table 2.4. Scale of humidity index W of the Vorobjov classification

Index	**Range**	**Name for humidity index**
-3	-6.4 .. -5.0	Ultra dry
-2	-5.1 .. -3.6	Extremely dry
-1	-3.7 .. -2.2	Particularly dry
0	-2.3 .. -0.8	Very dry
1	-0.9 .. 0.6	Dry
2	0.7 .. 2.0	Fresh

3	2.1 .. 3.4	Moist
4	3.5 .. 4.8	Damp
5	4.9 .. 6.2	Wet

Table 2.5. Scale of heat index T of the Vorobjov classification

Index	**Range**	**Name of corresponding forest type or non-forest zone**
a	24-44	Bor (original name in Russian)
b	45-64	Subor (original name in Russian)
c	65-84	Sugrud (original name in Russian)
d	85-104	Grud (original name in Russian)
e	105-124	Steppe
f	125-144	Dry steppe
g	145-164	Semidesert
h	165-184	Deserts

The correspondence of Vorobjov climate classification and Holdridge model is shown at Fig.2.7. The digram of Fig. 2.8 is the Vorobjov classification for the period 1961-1990.

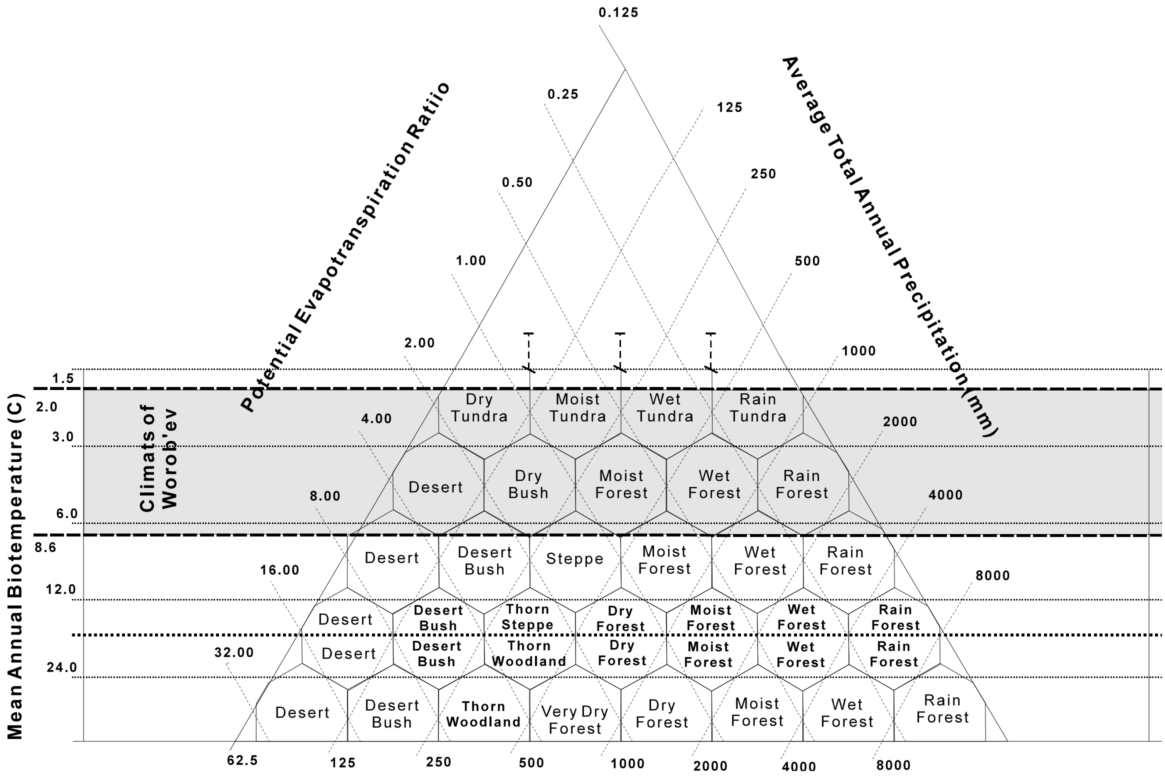


Fig. 2.7. Correspondence of Vorobjov climate classification and Holdridge model

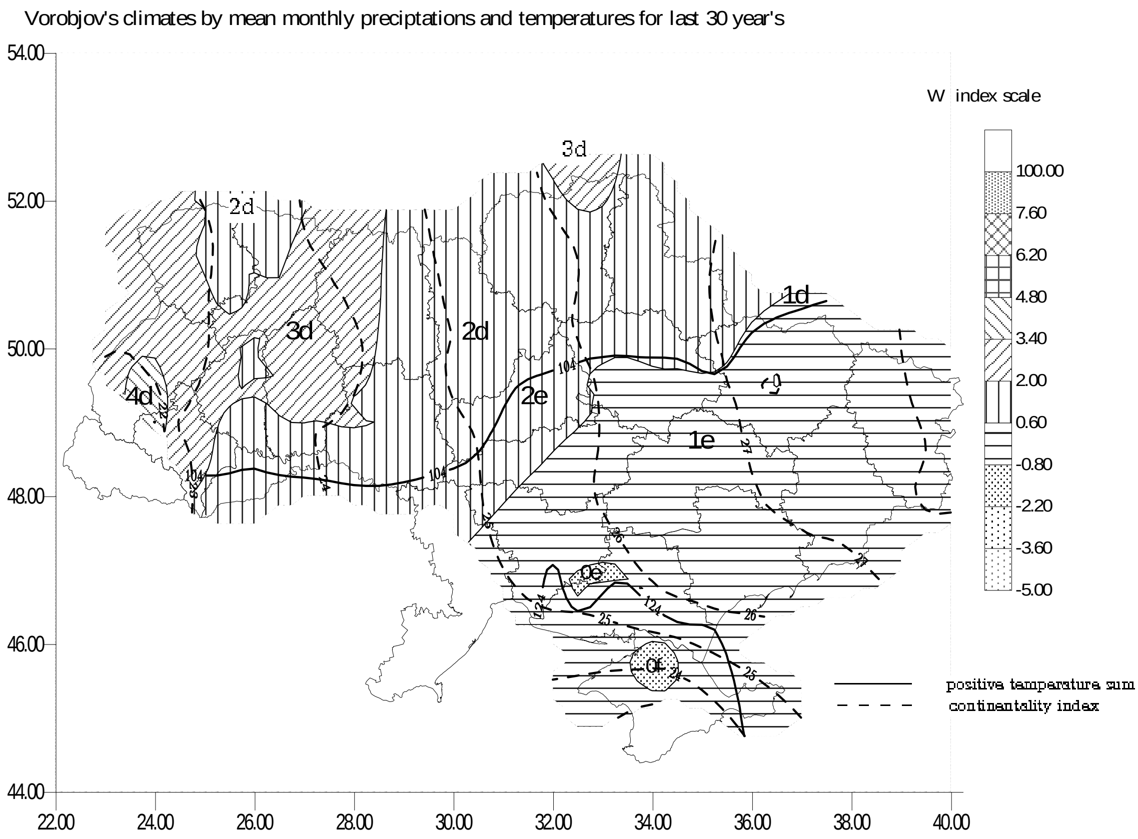


Fig. 2.8. Vorobjov's climate classification by forest types (on the real data from 66 meteorological stations for period 1961 – 1990)

Climate change scenario which has been used in frame of US Country Studies Program for studies of climate change in Ukraine (1994-1996 years) are as follows:

- CCCM – model of Canadian Climate Centre;

- GFDL – model of Geophysical Fluid Dynamics Laboratory;

- GISS – model of Goddard Institute for Space Sciences;

- UK89 – model of United Kingdom Meteorological Office.

Different predictions of scenarios according to different models (Fig. 2.9 and Fg. 2.10):

- CCCM scenario for the areas which cease to be forest there will be stands disintegration and partial change of species composition. Forest management affectivity will decrease due to aridization. Forest types and species composition will change in forest lands too, which will lead to a decrease of main forest-forming species productivity. After stabilization of new forest composition, productivity can increase in the northwest of Ukraine and decrease in the east;

- GFDL scenario provides changes as previously mentioned but the area with dry sites will be somewhat less;

- In case of GISS scenario climate conditions will be favorable to forest growth and expansion. Zone of steppe forest recultivation will decrease and forest zone area and its productivity will increase after stabilization. However, drastic climate change will be the cause of large-scale pest and diseases invasion and result in the cessation of natural forest renewal;

- According to UK89 scenario forest type diversity will increase. The forest boundary will move southeast, species composition will change to a small degree, and forest productivity will somewhat increase.

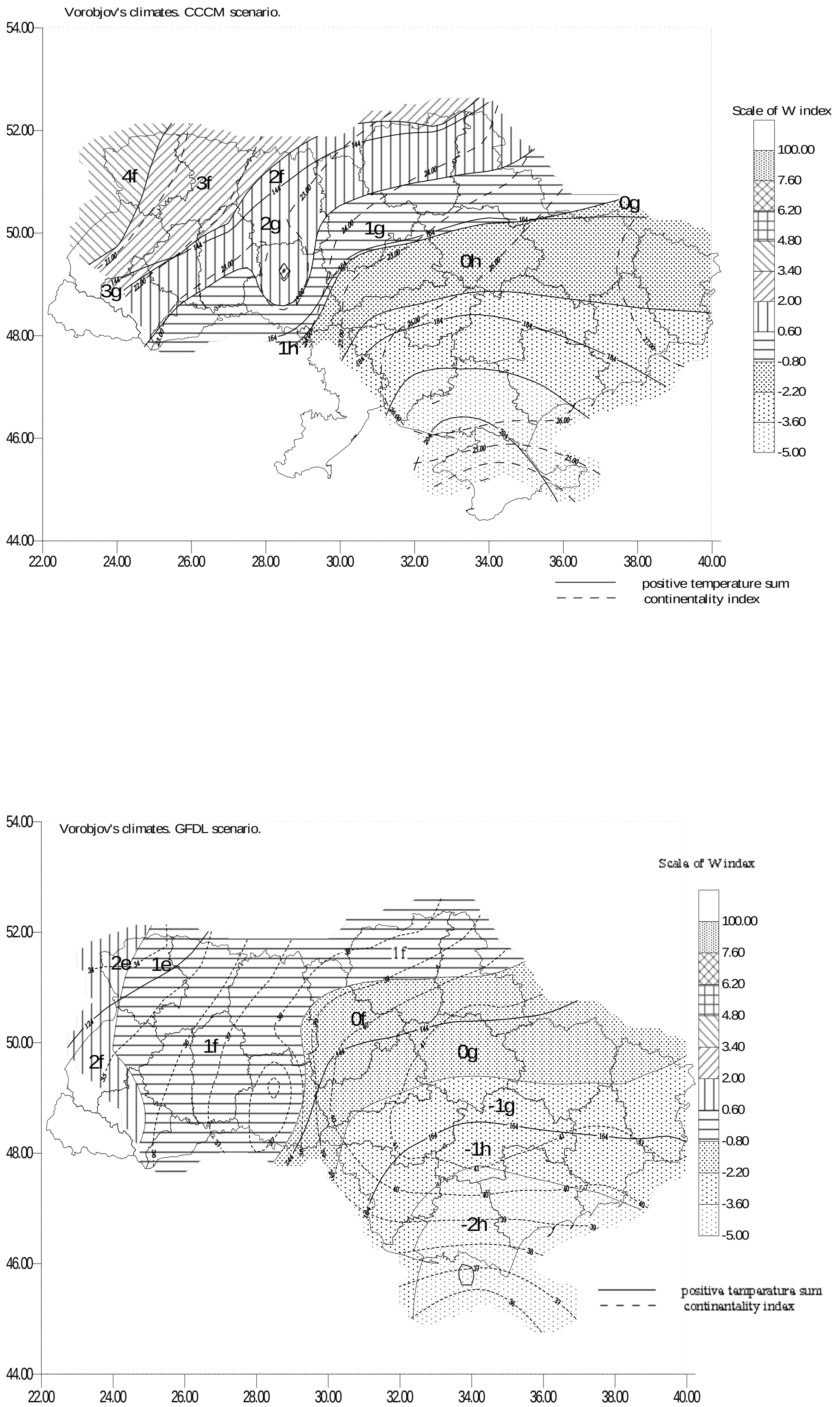
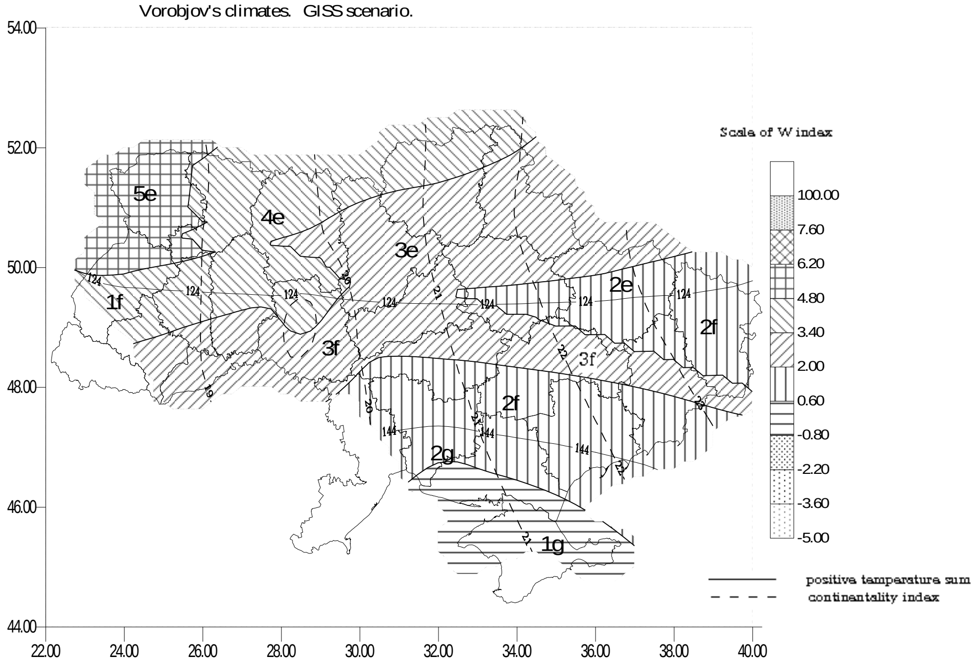


Fig. 2.9. Vorobjov’s climates according to CCCM scenario and GFDL scenario



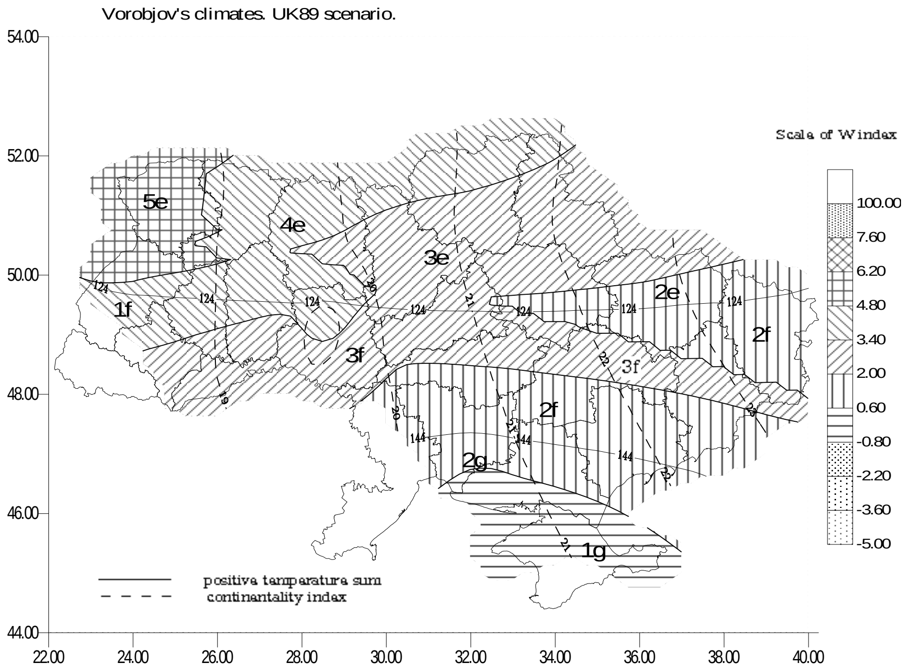


Fig. 2.10. Vorobjov’s climates according to GISS scenario and UK89 scenario

3.4. Discussion and conclusions

The above assessments show that the effects of long-period climate change will very likely be mostly negative for vegetation ecosystems and particularly for forests. Even for moderate predictions, the expected climate indicators would reach a level the country's forests have never experienced during the last several thousand years. Current science does not have knowledge on the behavior of forest ecosystems, their responses and feedbacks under such conditions.

Taking into account that Ukraine is situated in five different climatic zones, the consequences of the expected climate change will vary in different regions. By estimates, increase of temperature by 1^{o}C leads to the shift of latitudinal boundaries of climatic zones at 160 km [4]. Increasing evaporation may lead to increasing processes of desertification in some regions (e.g., on sandy soils of Polissya). Elevated temperatures will intensify the decomposition of humus and decrease soil fertility. Finally, it will result in the decreased vitality and resilience of forest ecosystems.

In areas with sufficient humidity it should lead to the increase of productivity of forests. Many studies predict an increase of productivity due to elevated concentrations of CO_2 in the atmosphere [5,6,7,8]. However, water stress could change this response significantly [9]. Quantification of the future productivity of Ukrainian forests is rather uncertain due to complicated interactions of new climates, CO_2 fertilization effect and nitrogen deposition and many unresolved questions that remain. There is not enough knowledge in understanding how forest ecosystems will function under multiple constraints on life resources under a substantially different climate.

In addition to clearly unfavorable climatic trends, the impacts of increased variability of climate on terrestrial ecosystems and particularly forests will be clearly negative and strong. Frequency of years during which forests (particularly in the southern part) will experience considerable water stress will increase. It will impact the vitality and resilience of forests, and very likely provoke large fires and outbreaks of dangerous insects. The latter is particularly dangerous for single species pine stands established on bare sands of *Pridneprov'ja* and other steppe regions. Increased fire danger is very likely in different parts of the region where forests are mostly presented by highly flammable pine stands. A specific and dangerous problems deal with forest fire in forests contaminated by radionuclides. Such fires provide secondary contamination of adjoining territories.

Overall, the expected major impacts of climate change on Ukrainian forests are diverse, zone, site and forest type specific and include:

- geographical and landscape changes in the location of areas suitable for the growth of certain tree species (shift or disappearance of some productive species);
- increases or decreases in stability and vitality of forest ecosystems, as well as changes in the production of timber and non-wood product per unit area; forecasts of the balance of the above processes for the region are mostly negative;
- changes in type, extent and severity of disturbance regimes (pest and diseases outbreaks, forest fire etc.);
- alteration of ecosystem ecological functions (e.g., impacts on biogeochemical cycles; impacts on biodiversity);
- increases or decreases in nutrient retention and turnover;

- changes in species' reproduction cycles and processes of maturation and aging, regularities of succession dynamics, and changes in environmental and social services (e.g., changing values of forest ecosystem as a tourist attraction; vitality and resilience of shelter belts; etc.).

Overall, expected impacts are mostly negative and require the development of special adaptation and mitigation measures. Considering the specifics and the role of the country's forests, adaptation and mitigation measures in the forest sector should be part of a wider strategy that should involve all relevant sectors of national economy, particularly energy, industry, agriculture, tourism etc. combined with common political and institutional frameworks.

Taking into account large uncertainties of future climate prediction, the adaptation and mitigation measures should be based on a conciliatory principle that would minimizes future losses due to insufficient current knowledge.

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