Assessment of the Climate Change Impact in the Bükk model area; results of the CC-WaterS project

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Abstract: This study analyses climate change induced possible changes in forest stands and water quality in Bükk Mountains model area (Hungary) as the part of the transnational CC-WaterS Project (Climate Change and Impact on Water Supply). The main objective of CC-WaterS project is to ensure sustainable and safe future water supply, which is influenced by climate change. Climate change induced possible changes of the main land use forest and water quality were examined. In order to evaluate changes of forest stands climate parameters were determined for each forest stand. Climate data of regional climate models (RCMs) were compared with the tolerance limits of forest stands for the periods 2021-2050 and 2071-2100. Thus spatial changes of forest stands were determined. Through different interception values, changes in the composition of forest stands cause changes in infiltration. These changes were calculated from the infiltration database of the area and the different interception values of forest stands.
Concerning water quality the main problem is high turbidity at waterworks after heavy rainfalls. Relationship between measured daily precipitation and turbidity data was examined; critical daily precipitation quantity – that causes turbidity – was determined. On the strength of future climate data of RCMs the number and intensity of extreme precipitation events in the present and future is comparable.
In the framework of CC-WaterS project these changes were integrated to a system of environmental indicators called DPSIR model (Driver-Pressure-State-Impact-Response) of Eurostat.

Key words CC-Waters, Bükk Mountains, climate change, forest stands changes, high turbidity, DPSIR-framework,

ABOUT CC-WATERS PROJECT

In the framework of the South East Europe Programme, the main objective of the transnational CC-WaterS project (Climate Change and Impact on Water Supply) is to ensure sustainable and safe future water supply, which is influenced by climate and landuse changes. Eighteen partners from nine south-eastern countries are participating in the project, each partner located one or more model areas. One of the Hungarian test areas is Bükk Mountains. The Hungarian partner is Central Directorate for Water and Environment (VKKI) and the sub-contractor is Smaragd-GSH Ltd. Within the scope of CC-WaterS project, important aims are estimating climate change induced possible changes in land use and water quality and calculating water supply for periods 2021-2050 and 2071-2100 in the Bükk Mountains model area. The reference period was 1961-1990. In the present study we focus on the applied methods and results on the possible changes in land use (forest stands) for periods 2021 2050 and 2071-2100 in the Bükk Mountains model area.

RESULTS OF REGIONAL CLIMATE MODELS (RCMS)

In the framework of Work Package 3 of CC-WaterS Project, the climate change modelling was carried out by J. Bartholy and R. Pongrácz (Eötvös Lóránd University). ALADIN and RegCM RCMs cover time period 1951-2100, PROMES model covers only time interval of 1951-2050. For all the climate change evaluations, bias corrected RCM outputs have been used. Projected seasonal precipitation changes are summarized in Fig. 1.

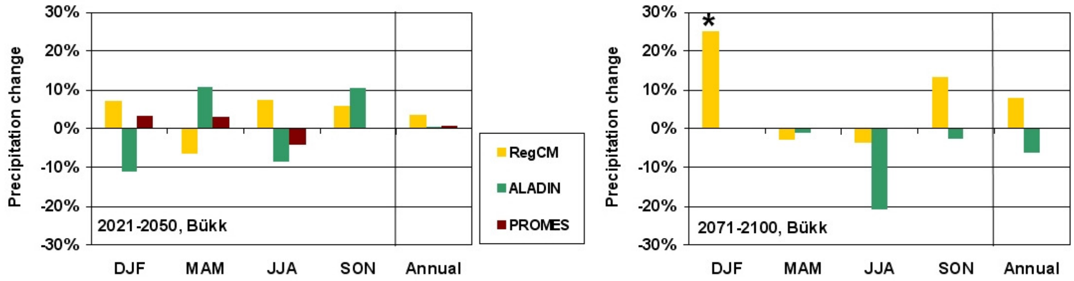

Fig.1 Projected seasonal mean precipitation change (reference period: 1961-1990). Significant changes (at 0.05 level) are indicated by asterisks.

Projected seasonal mean temperature changes are summarized in Fig. 2 for all the three RCMs.

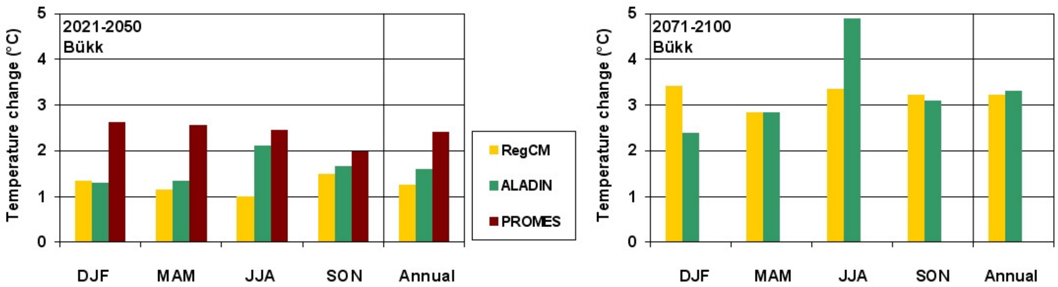

Fig. 2 Projected seasonal mean temperature change (reference period: 1961-1990). All projected changes are significant at 0.05 level.

BÜKK MOUNTAINS MODEL AREA

Bükk Mountains mainly consists of well developed karst limestones. Its thickness can reach a few thousand metres and stores significant amount karst water of excellent quality. Triassic limestone rocks of the Bükk constitute a continuous karst water reservoir to the verge of the mountain where the reservoir dips to depth of a few thousand metres in the area of the basin. Except of the south-western part that is covered by younger sediments, Bükk is an uncovered karst terrane while at the basin area the reservoir is under pressure. The covered and the uncovered parts of the karst terrane consist of a hydraulically uniform system; water yielded from the uncovered part – though not belongs to the test area – has influence on the processes taking place in the test area. Recharge of the karst system solely derives from precipitation falling on the area of the Bükk Mountains.

Characteristic of the springs directly discharging the karst terrane is the wide range of yield. The yield of the springs depends on geology, extent of the watershed, thickness of epikarst and size of the fissures and caves. These are intermittent springs, their yield strongly depend on the precipitation that directly recharges the karst system. For this reason karst system is the most sensitive system regarding climate change, mostly changes in the quantity of the precipitation. The yields of springs have seasonal variation as well; the highest yields are typical in March and April, after snow melting, while the lowest yields are characteristic in August and September.

Extremely high yields of the karst springs can be measured due to intensive rainfalls in May and summer when karst system fills in. Water resource of the springs supplies two kinds of needs. On the one hand it covers ecological water demand of the streams, on the other hand springs with high yields serve as water supplies. Unutilized water of these springs is introduced to the stream beds in the greatest part of the year. Derived from the above mentioned that yield of the streams is strongly varying. In summer the streams frequently desiccate.
Yearly average quantity of the recharge in Bükk Mountains is 102.551.155 m3. Quantity of natural discharge is 73.321.873 m3/y. Water directly yielded by supply wells is 5.338.128 m3/y. Subsurface lateral outflow from the test area is 23.91.154 m3/y (SMARAGD-GSH Kft., 2008). On regional scale the subsurface outflow belongs to subsurface exploitable resource, but the exploitable resource must always be investigated in local scale. 45 % of the natural discharge is utilized by spring waterworks.

DPSIR FRAMEWORK

In the framework of CC-WaterS project, the main aim of Work Package 5 was to estimate climate change induced possible changes in land use and water quality to 2100 and to integrate these changes to a system of environmental indicators called DPSIR model (Driver-Pressure-State-Impact-Response) of Eurostat. Application of DPSIR model for Bükk Mountains model area is depicted in Fig. 3.

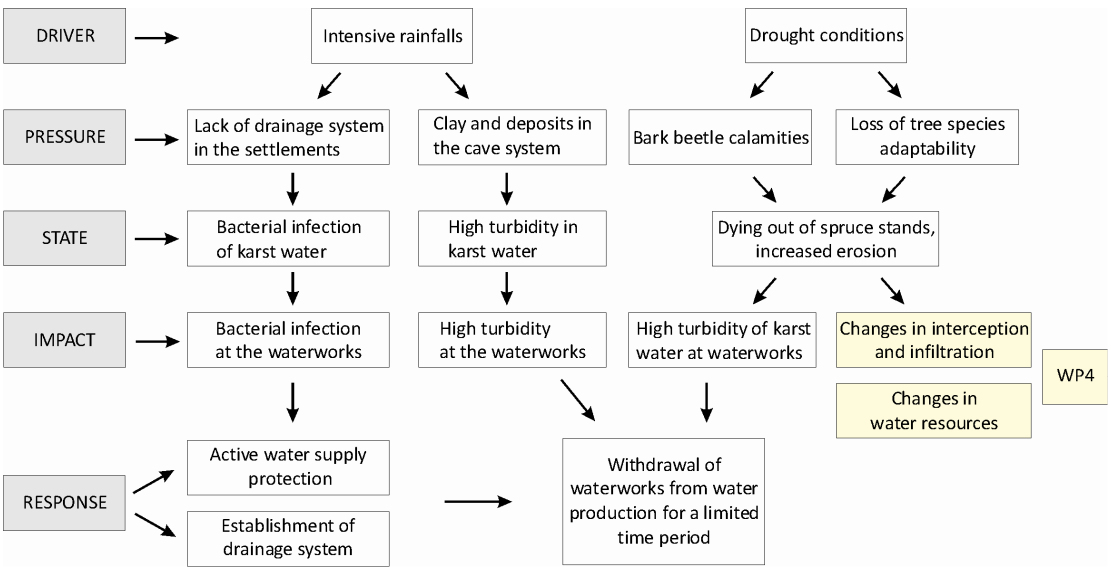

Fig. 3 Applied DPSIR model for the Bükk Mountains model area

CLIMATE CHANGE INDUCED WATER QUALITY CHANGES

During investigation the indicators of DPSIR model the first task was to identify current drivers that have effect on water quality. Based on data provided by climate change models the next step was to identify climate change induced drivers that may have future effect on water quality.
Taking into account the current water quality problems, high turbidity and bacterial infection of the water (IMPACT), we made an effort to identify the different processes (DRIVER) that result in the problems. We made investigations on the following current processes (drivers): heavy rainfalls, drought conditions and bark

beetle calamities. After identifying the drivers, based on available empirical data (temperature and precipitation, turbidity, forest stand distribution, bark beetle calamity) we made an attempt to quantify their possible effects.

DRIVER: heavy rainfalls

Based on measured precipitation data from 1961-1990, and modelled precipitation data for 2021-2050 and 2071-2100, we made estimations on the number of rainy days and precipitation intensity. According to the results both number of the precipitation events and amount of precipitation will presumably increase (Fig. 4) that will influence karst water quality, turbidity and bacterial infection of the karst water.

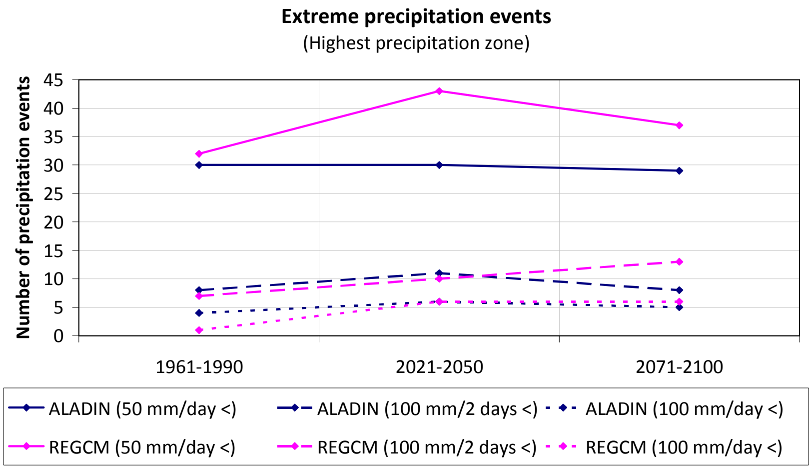

Fig. 4 Estimation of number and intensity of future extreme precipitation events

Driver that causes high turbidity of karst water is heavy rainfall. During heavy rainfalls (DRIVER), flood passes through the cave system and carries large amount of floated clay and deposits (PRESSURE) together with consolidated sludge in the cave system itself (STATE) that results high turbidity in the waterworks (IMPACT). As a result karst spring waterworks must be discharged for a limited time period. At Miskolctapolca waterworks high turbidity is a current problem. Karst spring waterworks are discharged (RESPONSE) when turbidity rises above 10 NTU. From November of 2006 on an automatic turbidity measuring and recording device (HACH Longe 1720 E) is operating in the karst spring that records turbidity values in every half minute. If there is any problematic increase in turbidity the karst spring waterworks is discharged from water production.

According to measured daily precipitation and turbidity data we can state that high turbidity above 10 NTU presumably occurs if precipitation reaches or exceeds 100 mm in two days.

Critical situation may arise when long (monthly) intervals with large amount of precipitation or heavy rainfalls (DRIVER) occur. These situations may result in – on account of lacking of precipitation conducting system – filling of the drainage system at the area of settlements. When the system fills in, contaminated mixture of precipitation water and sewage water overflows and gets to the surface. If the contaminated water gets into a stream and to a sink-hole or fault system, it can get to the karst spring waterworks within a few days.

Based on occurred event, heavy rainfall that caused flood resulted in increased runoff in the Bükk Mountains. As a consequence, high amount of precipitation water washed the slopes of the mountain and got to the valleys where passed through the area of villages and got to the stream in a valley. Well-known fact is the occurrence of sink-holes and fault system in the karst terrane of Bükk that conducts water to waterworks within a few days. Precipitation water washed down the surface in the area of the villages where keeping of livestock – therefore manure accumulation – is typical (PRESSURE). Through sink-holes, the contaminated water got to the karst system. This led to the bacterial infection (dramatic and sharp increase of contaminants) of karst water (STATE). Main contaminants were Coliform, E.coli, Enterococcus and Pseudomonas aeruginosa. The infected water got to the karst spring waterworks in a few days (IMPACT) and when they discharged the waterworks (RESPONSE), the water – that was already contaminated – was produced to plumbing.
Effect of heavy rainfalls on the concentrations of the main components is not detectable. The extent of the potential increase of contaminants due to heavy rainfalls is not known. Concerning water quality, in the Bükk Mountains increased turbidity and bacterial infection of the water due to floods (increased karst water level) are the main hazards.

DRIVER: drought conditions

We examined the effect of bark beetle calamity (PRESSURE) in the area of Bükk Mountains. Based on the occurrence and extent (empirical data) of bark beetle calamities and yearly precipitation data it is evident that bark beetle calamities occur after dry years (DRIVER). Generally we can say that if the yearly precipitation is below 70 percent of the yearly average precipitation (754 mm for eastern Bükk), bark beetle calamity may occur in the next year. Bark beetle calamity impairs spruce forests. As a consequence of dying out of spruce stands, forest stands become open in the following year that causes increased erosion in the area (STATE). Soil erosion results in high turbidity in the waterworks (IMPACT).
In Bükk Mountains the ratio of spruce forest stands is very low (2.1%) and are present in smaller patches in extended hornbeam oak forest. Furthermore spruce is not part of the potential natural vegetation. In our opinion further decrease of spruce stands will not remarkably influence the rate of erosion and turbidity of karst water. According to our calculations beech and oak forest will extend to the area of former spruce forests stands.

CLIMATE CHANGE INDUCED FOREST STANDS CHANGES

The most characteristic land use of Bükk model area is forest consisting mainly mixed beech, oak and spruce forest stands (all together 57 tree species). The territory of forests is more than 70 percent of the model area. Most of the area consists of Bükk National Park; forest management is operated by two sylvicultural companies.
The actual data concerning forest stands are originated from the Bükk National Park Directorate. After investigation interception data of forest stands in the literature (this chapter, explained later), this database was simplified to the most important zonal forest stands. These are: beech forest (Fagetum), hornbeam-oak forest (Querco petraeae-Carpinetum) and turkey oak-sessile oak forest (Quercetum petraea-cerris) and spruce forest (Piceetum abietis). Spruce forest is not indigenous in the model area. The simplified distribution map of forest stands is shown below in Fig. 5.

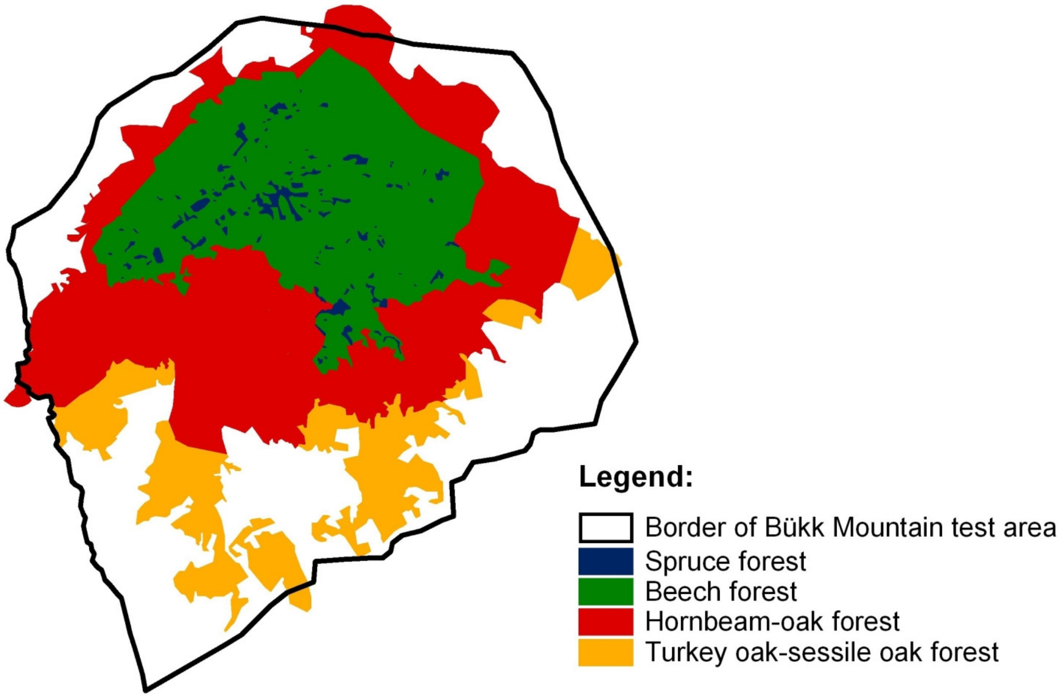

Fig. 5 Simplified forest stand distribution map, Bükk Mountains model area

In order to evaluate changes in forest stands we considered the present state. The first step was to determine climate parameters (limits) for each forest stand for Bükk model area. These parameters (limits) are yearly total precipitation [mm] and yearly average temperature [°C]. These data originate from a database which was used for an earlier project in Bükk Mountains (measured data between 1951 and 2006). These monthly data were the base of the interpolated yearly average total precipitation and yearly average temperature maps. Using these two interpolated maps and the forest stand map, an intersection map was constructed.

Each point of this map has 3 attributes from which we selected the border points' data of forest stands. These data shows the distribution limits of the given forest stand (Fig. 6).

Y-axis shows the average yearly temperature while X-axis the total yearly precipitation. In order to make a comparison between the distribution limits of forest stands in Bükk Mountains and generally in Europe we used the method of Kölling (2007). Dark patches in Fig. 6 represent the distribution limits of forest stands in Bükk Mountains model area. One can see that spruce forest is in extreme position, close to its tolerance limit. The other forest stands are stable.

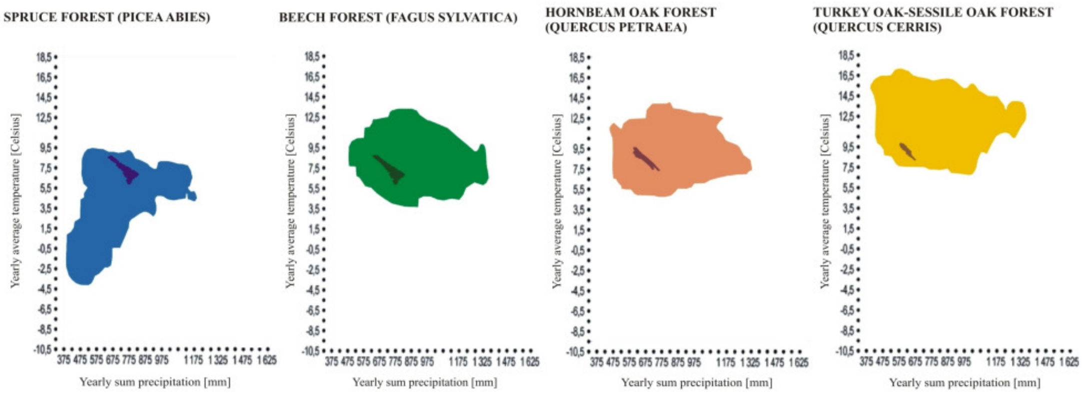

Fig. 6 Distribution limits of forest stands, Bükk Mountains model area

In the followings we present the methodology of estimation of changes in forest stands for periods 2021-2050 and 2071-2100 in the Bükk Mountains model area. The reference period was 1961-1990. For future analysis we used precipitation and temperature data provided by the chosen climate model (ALADIN). The modelled average values were the base of the interpolation which generated precipitation and temperature data for each point of the model area. These values were joined to forest stands.

Figures 7, 8, 9 and 10 depict shifting of climate parameters of forest stands. Changes of spruce forest stands will be the most significant (Fig. 7). The species is not indigenous and has not wide tolerance on dry climate. Dry climate will induce bark-beetle infestations in the future that may generate clear cutting in the affected area. Since climate presumably will be inconvenient for spruce, spruce forests must be changed to beech forests in the future. The area of spruce forests will decrease by 57 percent in the 1st future period. To 2100 (2nd future period) only 12 percent (144 hectares) of the current extension (1180 hectares) will remain.

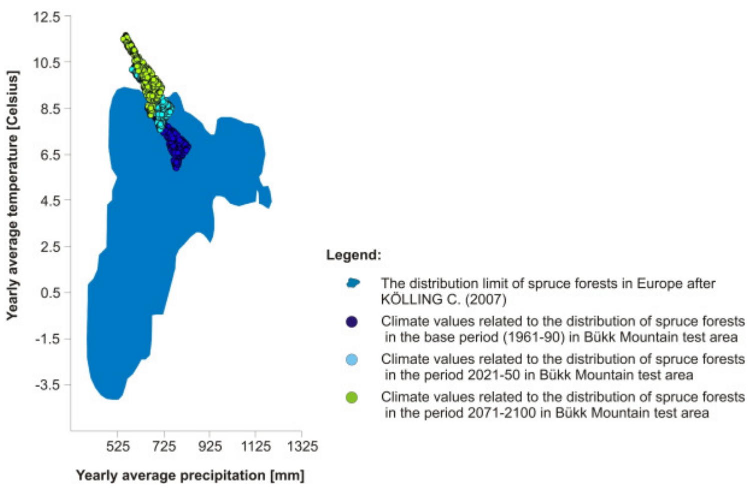

Fig. 7 Modelled climate values related to spruce forests

Change of beech forests' area is theoretically positive (+ 500 hectares) in the 1st future period. The reason is the damage of spruce forest stands. Of course species changing process doesn't come off in one or two years, it needs longer time. This is why change of the area of beech forests will probably be stagnant in this period (Fig. 8). Intensive drying process is presumably going to come up in the 2nd future period which will have outstanding effect on beech forests. Subsequently foresters probably have to make changes in forest stands from beech to hornbeam oak forests in the lower zones. Beech forests' area will decrease only with 320 hectares (1.6 percent).

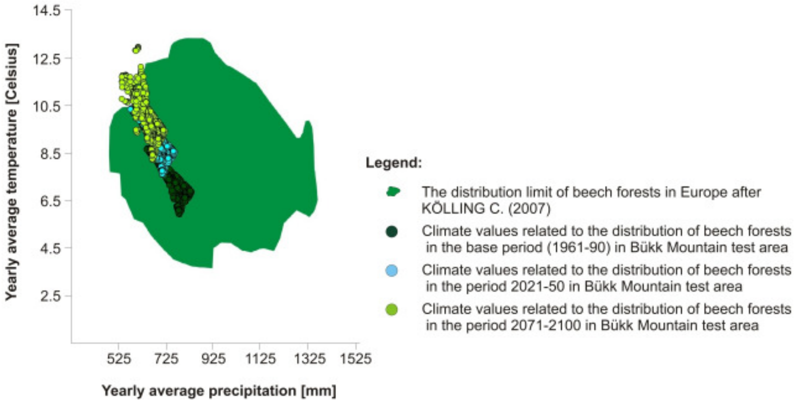

Fig. 8 Modelled climate values related to beech forests

No predictable changes are expected in the area of hornbeam oak forests in the 1st future period. In the 2nd future period hornbeam oak forests will show low extent spreading in beech bordering zones. In the lower zones of hornbeam oak forests turkey oak-sessile oak forests will appear. The area of the forest stand will increase with 71 hectares to 2100 (Fig. 9).

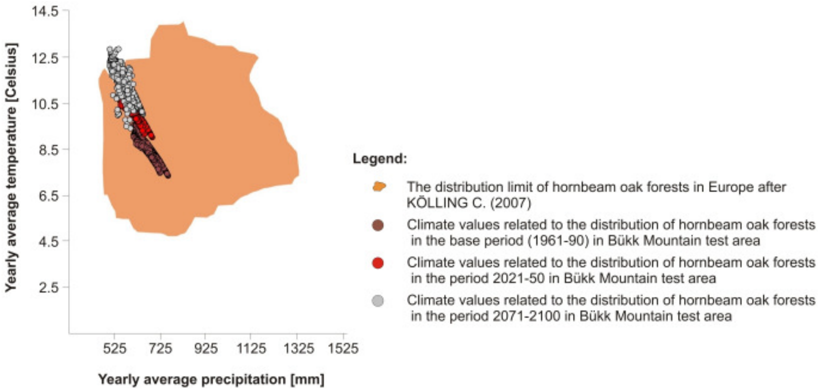

Fig. 9 Modelled climate values related to hornbeam oak forests

Intensive drying processes are favourable for turkey oak-sessile oak forests. Spreading of this forest stand shows high extent. The area of the forest stand will increase with 1300 hectares, 13 percent of the present area (Fig. 10).

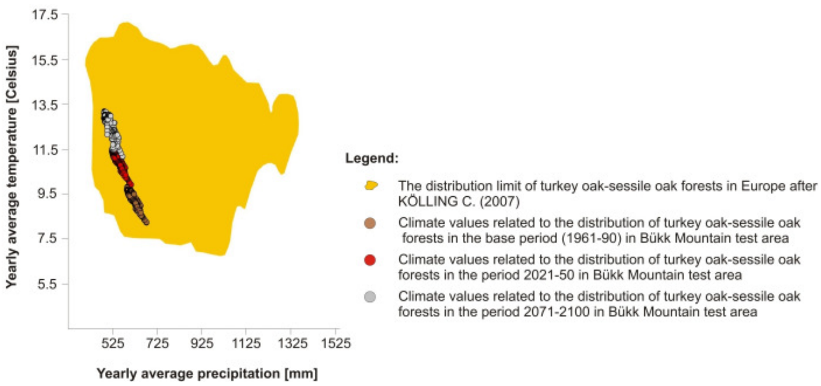

Fig. 10 Modelled climate values related to turkey oak-sessile oak forests

Each point in Fig. 7, 8, 9 and 10 has an ID so it's easy to identify which area will change. Fig. 11 shows the changes in the area of forest stands on the strength of changes of average climate values.

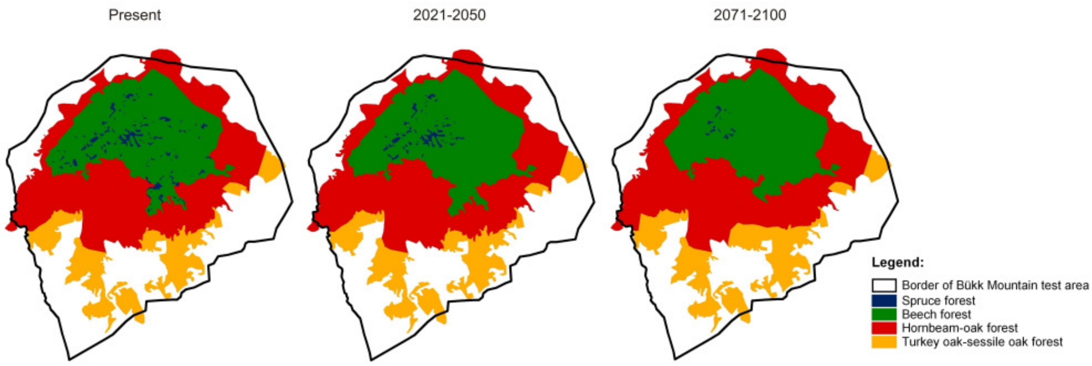

Fig. 11 Present and future forest stand distributions, Bükk Mountains model area

Changes in forest stands will cause changes in infiltration (IMPACT). These changes were calculated from the analysis above and from data of former interception researches. During our calculations we applied the measured and published data of Führer (1992). This research calculates with the interception of forest-litter, too. Table 1 shows the infiltration values of forest stands compared to precipitation.

Table 1. Infiltration values of forest stands compared to precipitation in percent form (Führer, 1992)

Forest stand	Infiltration compared to precipitation [percent]	Location	Period
Beech	54	Sopron Mountain	1988-90
Oak	44	Sopron Mountain	1988-90
Spruce	42	Sopron Mountain	1988-90

Changes of forest stands need long time. This is why calculations were made only for the period 2071-2100. Calculated changes are only arisen from changes of forest stands. The direct effects of climate change are not considered here. Infiltration changes were calculated for the test area (East-Bükk) on which forest stands will change in the future. For calculation of the changes of infiltration we used a detailed average infiltration database of a former project (contains more than 500 infiltration categories). Infiltration map and the map which shows the changed forest stands were intersected. From this intersection we could select the infiltration categories which are changed. We calculated the areas of the changed polygons and corrected the infiltration values of the changed categories according to changes of forest stands (changes of interception). After values in Table 1 we used the following correction factors (Table 2).

Table 2. Correction factors for calculating changes of infiltration

Change	from spruce to beech	from spruce to oak	from beech to oak
Correction factor	1.28	1.05	0.81

The area of the category multiplied by the corrected infiltration value results the changed yearly infiltration volume of the category.

According to our calculations, changes of spruce forest stands to beech result 400 000 m3 extra infiltration in an average year. In lower zones beech forests will change to oak which results 120 000 m3 deficit in water balance.
Summarizing the above mentioned it can be stated that water balance will probably increase with 280 000 m3 arisen from changes of forest stands in an average year. In proportion to the average yearly infiltration of the area it means 0.27 percent extra infiltration. Subsequently changes we stated above will be advantageous for water balance and water management.

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