



Afforestation for Restoration of Land and Climate Change Mitigation

Authors

Imre Berki

András Bidló

Áron Drüszler

Attila Eredics

Borbála Gálos

Csaba Mátyás

Norbert Móricz

Ervin Rasztovits

University of West Hungary

Bajcsy-Zs, 4, H-9400

Sopron, Hungary

Reforestation under climate change in temperate, water limited regions: current views and challenges

Csaba Mátyás

ABSTRACT

The ecological benefits of forests and afforestation at the sensitive lower edge of the closed forest belt (at the “xeric limits”) are still disputed. Forests control erosion, dust storms and silting of streams but may reduce stream flow and reduce groundwater table level due to higher water use with consequences for water management. The forest/grassland transition zone is especially vulnerable to projected drastic temperature and precipitation shifts in the future. In spite of contrary expectations, the effect of forests and afforestation in improvement of regional climate conditions is restricted. Ecologically conscious forest policy and management requires the consideration of local conditions, of projections of future climatic conditions and also of non-forest alternatives of land use. The chapter investigates some of the relevant aspects of the ecological role of forests at the dryland edges on the example of three countries/regions on three continents.

1 INTRODUCTION

In the drought-threatened regions of the Eurasian and North American forest steppe¹ zone, reforestation and afforestation² has been long considered as crucial in rehabilitating of degraded, over-exploited lands, in stabilizing water supply, reducing desertification and in improving regional climatic conditions.

However, the generally positive effects of afforestation on regional climate and water resources are presently debated. Due to the limited understanding of interactions between physical processes and land cover, the dispute is still unresolved (Ellison et al. 2011), although the opinion prevails that in the forest steppe zone, water consumption of man-made forests might contribute to water scarcity and aridification, and may not achieve the goals of environmental protection (Jackson et al., 2005; Sun et al., 2006; Andréassian, 2004; Brown et al., 2005; Wang, Y. et al., 2008). Projected changes in global climate pose a further challenge on dryland ecosystems, as relatively small changes in the moisture balance may lead to considerable ecological shifts. Forests may even become a factor of increasing climate forcing (Drüzler et al., 2010; Gálos et al., 2011; Mátyás et al., 2009).

1.1 Climate, water and forests

Precipitation and temperature are the ultimate drivers of vegetation distribution on earth. Globally, zonal forests are generally found in areas where annual precipitation exceeds evapotranspiration, and thus forests are both dependent from and the sources of surface water resources. For example it is estimated that 50% of US water

¹ Forest steppe is the transition zone to grasslands where (natural) forests largely depend on locally accessible surplus water

² The terms afforestation and reforestation are used in this paper largely as synonyms. I.e. the question of original vegetation cover is left unconsidered, as it is difficult to assess it in landscapes under heavy human influence

supply comes from forest lands (Brown et al., 2008). Water use by temperate forests is generally less than 700 mm during the growing season, suggesting that ecosystem water use (tree transpiration + evaporation) is limited by energy and water availability (Sun et al., 2011a, Fig. 2). Analyzing temperate grassland and forest sites in the USA, Sun et al. (2011a) found that in the warm-temperate zone forests require at least 400 mm of precipitation in the growing season to sustain desired functions, and grassland and scrublands are found at sites where growing season precipitation is below 400 mm (Fig. 1). Interestingly, atmospheric precipitation was barely sufficient for most ecosystems among the 16 ecohydrological study sites in the USA, with only one exception in the humid subtropical region (Fig. 1).

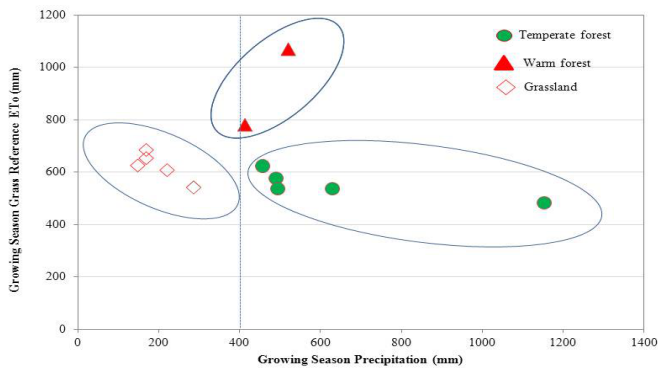


Figure 1. Growing season precipitation and grass reference evapotranspiration (i.e., P-ET) are major drivers for zonal vegetation distribution. Data are derived from an ecohydrological study with sites in the United States, China, and Australia. The figure shows grassland sites (cold steppes and milder-climate shrublands), poplar plantations where precipitation exceeds 400 mm (warm forests), respectively temperate forest sites (Sun et al., 2011a, Mátyás, Sun and Zhang 2013)

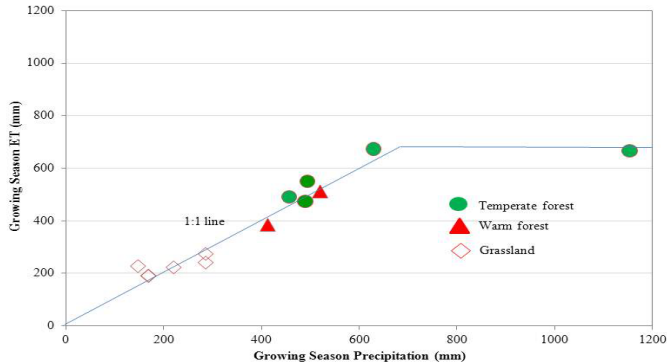


Figure 2. Water use (growing season evapotranspiration vs. precipitation) of grasslands and forests across ecohydrologic study sites (Mátyás, Sun and Zhang 2013)

2 EFFECTS OF FORESTS ON HYDROLOGICAL BALANCE IN DRY REGIONS

Compared to grasslands or short-cycle crops, forests have large above-ground biomass and deeper roots, therefore can use more water (Wang, Y. et al., 2011) and can capture larger amounts of carbon through photosynthesis as carbon and water cycles are highly coupled (Law et al., 2002; Sun et al., 2011b). World-wide vegetation manipulation experiments show that forest removals reduce water use, i.e., evapotranspiration (ET), and thus increase watershed stream flow. On the other hand, reforestation or afforestation on watersheds previously covered by native grassland can reduce stream flow due to an increase in ET (Andréassian, 2004). Forests have higher ET than harvested sites or croplands, so groundwater table levels are generally lower under forests (Sun et al., 2000, see also Fig. 3).

Earlier long-term forest hydrologic studies focused on deforestation effects, floods and sedimentation (Alila et al., 2009). Hydrologic studies on the consequences of afforestation have emerged in the past decade (Scott et al., 2005; Sun et al., 2006;

Wang, Y. et al., 2011). In particular, evaluation of worldwide reforestation campaigns has shown that human intervention requires a closer look at the unexpected consequences. An emerging question is how reforestation in different climatic regimes affects watershed functions such as water yield (Sun et al., 2006). The potential water yield reduction following afforestation for bioenergy development, ecological restoration, respectively for climate change mitigation, has drawn renewed attention to the relations between forests and water resources in watersheds (Calder, 2002; Brown et al., 2005; Jackson et al., 2005; Trabucco et al., 2008; Malmer et al., 2009) and on a regional scale (Ellison et al., 2011). The hot debate on 'planting' or 'not planting' policies is especially relevant in arid regions or regions with scarce water resources (Greeff, 2010).

2.1 China: landcover changes and effects on streamflow

Comprehensive forest hydrological studies that address forest-water relations did not start until the 1990s. Important findings emerged rapidly in the past two decades (Wei et al., 2008). In dry Northern China, such as the Loess Plateau region, empirical and modeling studies confirm that forest vegetation and associated soil conservation engineering had significant influence on watershed stream flow (Zhang et al., 2008a; 2008b; Wang, Y. et al., 2011; Wang, S. et al., 2011).

Recent forest hydrology studies have detected that land cover and land use changes played a substantial role in stream flow reduction downstream (Zhang et al., 2008a; 2008b). A water balance modeling study suggests that if 5.8% and 10.1% of the study area on the Loess Plateau is planted with trees, stream flow will decrease by 5.5% and 9.2%, respectively. The rate of stream flow reduction decreased from dry to wet area in the Loess Plateau region (Zhang et al., 2008a). In another 40-year retrospective study (1959-1999), Zhang et al. (2008b) examined stream flow and climate data from 11 catchments in the Loess Plateau to investigate the response of stream flow to land use/cover changes. They found that all catchments had significant reductions in annual stream flow of -0.13 to -1.58 mm per year between 1971 and 1985. Land use/cover changes accounted for over 50% of the reduction in mean annual stream flow in 8 out of the 11 catchments while in the remaining three watersheds precipitation and potential evaporation were more important. Among the soil conservation measures, construction of sediment-trapping dams and reservoirs, and the diversion for irrigation appeared to be the main cause of reduced stream flow.

To understand the effects of vegetation on stream flow in the Loess Plateau region, Wang, Y. et al. (2011) constructed multi-annual water balances for 57 basins to estimate annual evapotranspiration (ET) and runoff for forest lands and non-forest lands. The authors argue that large-scale afforestation may have serious consequences for water management and sustainable development in dry regions because of runoff reduction.

2.2 United States: effects of landcover management

Since the late 1930s, numerous 'paired watershed' studies have been conducted in the United States to examine forest management effects (harvesting with various intensities, species conversion, farming as an alternative), on water quality and yield across various climatic and topographic conditions (Ice and Stednick, 2004). In general, humid areas with high precipitation have higher hydrologic response in absolute terms, but dry areas with low water flow can have a higher relative response. For example, clear-cutting a deciduous forest in the humid south-eastern US, with an annual precipitation >1800 mm, can result in an increase in stream flow of 130-410 mm per year, which is 15-40% of undisturbed control watersheds, while the same management practice in the drier area of northern Arizona with an annual precipitation of 500-600 mm may result in a water yield increase of 60 mm or >40% of undisturbed control watersheds. Zou et al. (2009) summarized century-long vegetation manipulation experiment studies in the Colorado River Basin that provide a bounty of knowledge about effects of change in forest vegetation on stream flow in water-deficit areas. The watershed is situated at the headwaters of streams and rivers that supply much of the water to downstream users in the western United States. The authors found that vegetation can be managed to enhance annual water yields while still providing other ecological services. The effects of vegetation manipulation on stream flow are associated with the precipitation/elevation gradient and, therefore, with vegetation type. An annual water yield increase between 25 and 100 mm could be achieved by implementing vegetation manipulation in the high elevation subalpine and mixed conifer forests, the lower ponderosa pine forests and portions of the low elevation chaparral scrublands. The annual precipitation was generally above 500 mm in areas where a 100 mm increase in stream flow was achieved. Negligible or small increases in water yield were observed from treating sagebrush, pinyon-juniper woodlands and desert scrubs, with an annual precipitation below 500 mm. This study suggests that reforestation is likely to cause relatively larger hydrologic effect in areas where precipitation is roughly balanced by evapotranspiration demand, i.e., above 500 mm.

2.3 Hungary: reforestation and its effect on groundwater resources

In the last century, large-scale reforestation programs changed the land cover of the Hungarian Great Plain, with the aim to improve not only timber supply but also the regional climate and hydrology of the largely treeless landscape. For example, on the Danube-Tisza Sand Plateau, a region of 828 thousand ha, forest cover increased in four decades from 5 to 26%. A debate between hydrologists and foresters about the true effects of reforestation led to numerous studies to investigate effects of forest cover on water resources.

Measurements confirmed that in areas where deep rooting forests can tap the groundwater, the evapotranspiration (ET) rate surpasses the amount of precipitation. On the Sand Plateau, with an average annual precipitation of 526 mm, ET was estimated from MODIS daytime land surface temperature data. Average annual ET of forests was estimated at 620 mm a⁻¹, which was about 80 mm more than the actual annual precipitation (Szilágyi et al. 2012). In a black pine plantation a mean annual ET rate of 712 mm a⁻¹ was registered by Major (2002) out of which 130 mm originated from the groundwater.

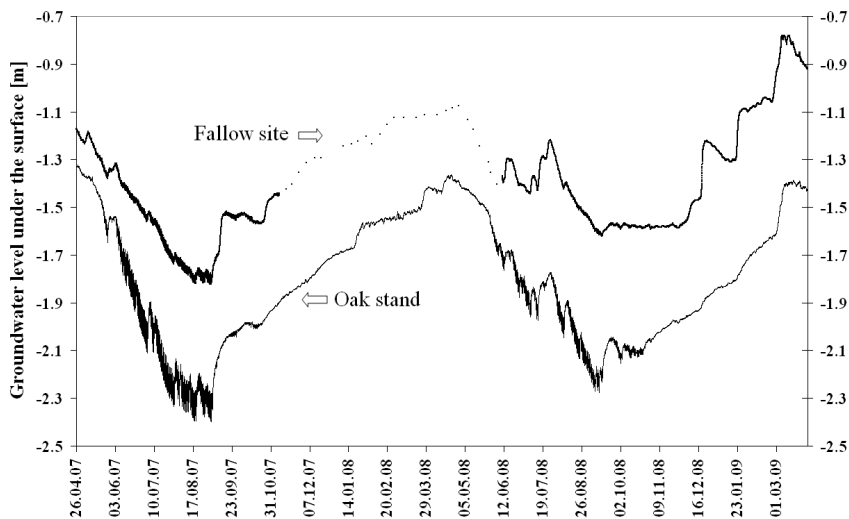


Figure 3. Water table fluctuation in the course of one year under an oak forest (*Quercus robur*) and a neighboring grassland (fallow) site in the forest steppe zone of Hungary (design: N. Móricz in: Mátyás, Sun and Zhang 2013)

In other studies the groundwater consumption of forest and of grassland was compared. In a somewhat less harsh climatic environment of 570 mm annual rainfall and a growing season precipitation of 360 mm (i.e. still a potential grassland climate according to Sun et al. 2011a), an oak forest had approx. 30% more annual evapotranspiration than a neighboring fallow (405 vs. 283 mm). The difference was however much higher in average groundwater use (oak: 243 mm, fallow: 85 mm). The groundwater consumption was close to 60% of the total transpiration of the oak forest and approximately 30% of the fallow. Groundwater consumption was approximately 40% less in a wet than in a dry growing season, despite the fact that the groundwater table was deeper during the dry period (Móricz et al. 2012).

Various measurements have shown that in shallow groundwater areas on the Danube-Tisza Sand Plateau forest vegetation may lower water table from 0.5 up to 1.1 m compared to the level below herbaceous vegetation (Major 2002). Under natural conditions, if maximum groundwater level (in April) is deeper than -2.5 m, grassland predominates in this climate.

Measurements revealed that in the Hungarian forest steppe climate zone, forest cover does not contribute to groundwater recharge or to runoff, and utilizes additional, near-surface groundwater resources. Due to lower groundwater levels under forests, local water table depressions develop, which may direct groundwater flow toward forested patches.

3 THE CHALLENGE OF CHANGING CLIMATE

3.1 The climatic transition zone at the forest/grassland edge

The climatic and biogeographic conditions of the continental plains of South-eastern Europe and of temperate Northeast Asia are very diverse, which is also true for their socio-economic statuses and current problems (i.e. land use change, soil degradation or desertification). What makes this region specific is the presence of the so-called *xeric limit* of forests and forest tree species.

Xeric (or rear, trailing³) forest limits are at the low latitude, low altitude end of distribution ranges of temperate forest trees, where presence or absence of (climate-) zonal, closed forests is determined by climatic aridity (Mátyás et al., 2009). Xeric limits appear in low-precipitation zones of continental plains, along the foothills of mountain ranges, and at the edges of dry basins in the temperate-continental climate. At the xeric limit, the closed forest belt forms a transition zone (ecotone) toward the open woodland or forest steppe, which dissolves with decreasing precipitation into the true steppe or grassland. The forest/grassland ecotone is dependent on a volatile minimum of rainfall and is therefore sensitive to prolonged droughts. The physical characteristics of the land surface (e.g., albedo, evapotranspiration, roughness etc.) as well as carbon cycle and ecological services are strongly affected by land use policy and changes in this area.

The forest steppe belt reaches from the plains of Southeast Europe and South Russia into Southern Siberia and North China. Temperate xeric limits exist also on other continents, along the edge of the Prairies of North America, notably from the southwest states of the USA northward into Alberta (Canada). In Southeast Europe, and also in China the transition zone is a densely populated and is an agriculturally important region which has been under human influence for millennia. On flat terrain, the climatic transition from closed forests to grassland is difficult to trace, due to variability of hydrological conditions and, first of all, due to strong human interference.

Forest ecologists in Eastern Europe distinguish a specific forest steppe (woodland) climate. According to Hungarian data, the zone classified into this category is characterized by an average precipitation of 563 mm per year, a July mean of 21,5 °C and a water deficit of 346 mm (Mátyás and Czimmer 2000). Scarce precipitation in the vegetation period (approximately 320 mm) and frequent summer droughts limit the presence of closed forests except to sites where supplementary water resources are available below ground. Forest crown interception and litter interception may further diminish available water resources even in more humid forested catchments (Gribovszki et al 2006). In forest steppe climate, loss through crown and litter interception can be up to 25-40%. Native, deciduous species have generally values under 30%, whereas conifer plantations intercept between 35 and 40% of the already meager precipitation (Járó 1980). Natural forest cover remains therefore patchy in this zone, indicating mosaics where groundwater influence improves site conditions.

³ The terms in brackets refer to events of postglacial migration, where xeric limits represent the "rear" end of shifting vegetation zones, triggered by gradual warming

3.2 The climatic vulnerability of the forest/grassland transition zone

The forest-grassland transition zone is especially vulnerable to expected climatic changes in flat lands because of the magnitude of the *latitudinal lapse rate*. It is generally known that the altitudinal lapse rate for temperature (i.e., the rate of change with increasing elevation) is 5.0 - 6.5 °C/1000 m. The latitudinal (south to north) lapse rate is less recognized. In the temperate zone its mean value is around 6.9 °C/1000 km - a difference of three magnitudes. This means that predicted changes of temperature affect disproportionately larger tracts of plains as compared to mountainous regions. A temperature increase of only +1 °C causes a shift upwards along a mountain slope of approximately 170 m. On a plain, the same change triggers a shift of close to 150 km (Jump et al., 2009). This explains the much greater vulnerability of rain-dependent vegetation on plains. Predicted changes may easily trigger the loss of already sparse forest cover, which may lead to the disruption of vital ecological services that the forests provide.

3.3 Recently observed climatic impacts

Across the temperate zone, a relatively rapid increase of annual mean temperature has been observed in recent decades, and the dryland zone in China and Mongolia is no exception. In the last half century, both average temperatures and climatic extremes increased (Qi et al., 2012). For instance, average temperatures in Mongolia increased by more than 2 °C since 1940 and nine out of the ten warmest years occurred after 1990 (Lu et al., 2009). In North China, frequency of droughts intensified during the past several decades, leading to an unprecedented increase of dry areas (Piao et al., 2010). Growing season anomalies have been generally increasing in China in the 2000s: drought events got significantly stronger in North China and soil moisture declined (Zhao and Running, 2010).

Numerous studies and also IPCC's 2007 report forecast a decline in growth and production of forests in dry regions. At the same time, analyses of impacts of climate on forests are limited or sporadic. For instance, FAO global statistics do not yet calculate with the effect of forest cover loss due to aridification (FAO, 2010). There are reports about observed impacts from western North America (Allen et al., 2010; Hogg and Price, 2000), while impacts in Eastern Europe, Central Asia and the Chinese Drylands are less known (Zhang et al., 2008b; Piao et al., 2010; Mátyás, 2010a). It

should be noted, however, that the reason for the missing evidence for impacts of gradually worsening ecological conditions has to be sought probably in improper data analysis. Specific experiments on growth and yield confirm the expected negative impact of rising temperatures on vitality and survival (Mátyás et al., 2010; Fig. 4).

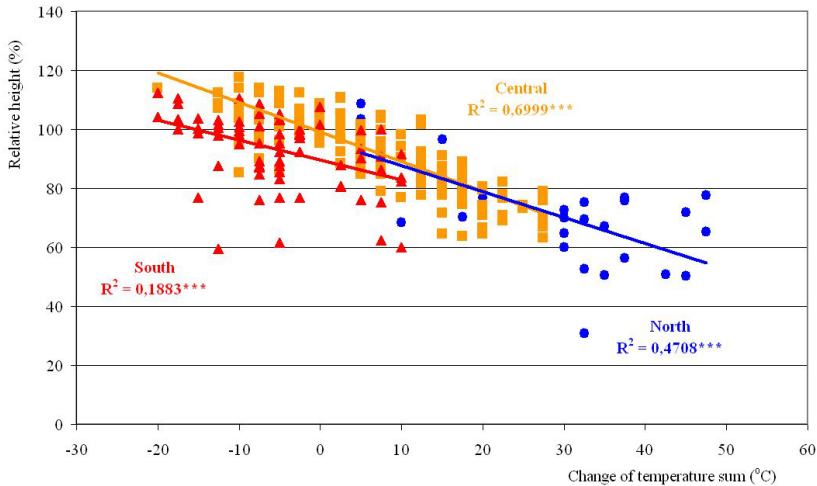


Figure 4. Growth response of geographically transferred Scots pine (*Pinus sylvestris*) populations (provenances) to simulated warming. The increase of annual temperature sum (in °C degree-days) resulted in a decline of relative height irrespective of origin (central, northern or southern populations). Re-analyzed data of six Russian experiments (Mátyás et al. 2010, Mátyás, Sun and Zhang 2013).

3.4 The hidden threat at the xeric limits: increasing drought

According to calculations of IPCC, projected temperature changes of the critical summer climate at the end of the century are more drastic in the forest/grassland transition zone than in the boreal zone of Eurasia. Projected summer precipitation decline and shifts in drought frequency is of special significance at the xeric limits which are extremely sensitive to even minor humidity variations. Mass mortality may appear, especially on sites with unfavourable water regime.

3.5 Considerations for forest management

In most temperate zone countries with drylands, instead of large scale afforestation with plantations, returning to close-to-nature forest management seems to be the general trend to mitigate impacts of environmental change (e.g. Xu 2011, see also Mátyás 2010a). The concept is based on the hypothesis that stability and persistence of forest ecosystems is warranted by plant communities having evolved during the past millennia, and enhancing the naturalness of forests will also enhance their stability. The hypothesis is challenged at the xeric limits by numerous constraints, such as

- long-lasting human interference and land use have caused a partial or total loss of natural (woody) plant cover, spontaneous processes of vegetation recovering might be very slow,
- number of native species expected to tolerate expected environmental changes is usually low,
- functioning of close-to-natural systems is disturbed by indirect human effects (e.g., grazing and game damages, air pollution) and by the projected climatic changes and extreme events.

These constraints necessitate a considerate revision of the commitment to naturalness, first of all in regions of high drought risk. It is believed that carefully planned and active human interference is unavoidable in dry lands because the long-term ecological and genetic effects of adaptation to environmental changes have to be considered.

A cost-effective, scientifically based forest policy in the forest steppe zone requires the consideration of local environmental conditions, of land use alternatives such as restoration of grasslands and scrublands, and the use of the proper technology. Experiences from the United States confirm that vegetation can be successfully managed to enhance annual water yields while still providing other ecological benefits. Carefully planned human interference is therefore essential, to achieve a successful policy of restoration and of adaptation to the expected environmental changes.

4 SUMMARY AND CONCLUSIONS

Current views and experiences about the role of forests at dryland margins are contradictory. Although forests provide multiple ecological benefits, reforestation or afforestation on watersheds previously used by agriculture or covered by grassland can reduce stream flow due to higher water use and may have serious for water management and sustainable development. In the forest steppe climate zone, forest cover does not contribute to groundwater recharge or to runoff, and utilizes near-surface groundwater resources.

Forest cover influences atmospheric climate forcing. Therefore it is believed that forests mitigate climate change impacts such as warming and aridification. Studies indicate that in spite of increased evapotranspiration, precipitation changes are only moderately even in extensively afforested regions. At the same time, the lower albedo of forests may even lead to minor temperature rise. It seems that the balance between albedo and actual evapotranspiration determines whether there is a cooling or warming effect.

The forest/grassland ecotone is dependent on a volatile minimum of rainfall and is therefore sensitive to climatic changes. Projected summer precipitation decline and shifts in drought frequency may easily trigger the loss of forest cover, which may lead to the disruption of vital ecological services that the forests provide. Because of the extreme long-term character of forestry, the consideration of projected future climate effects has to play a central role in management planning. Stability and growth of forests depend on humidity conditions of the future especially in the dryland transition zone. Concerns about hydrology and climate should be weighed when making decisions about land use changes. Studies confirm that proper forest management and associated soil conservation engineering have a beneficial influence on ecology of watersheds.

RELATED WEBSITES, PROJECTS AND VIDEOS

climatic role of forests: <http://www.youtube.com/watch?v=fwpfbDfKDMU>

Land Use, Land Use Change and Forestry (LULUCF): <http://forest.jrc.ec.europa.eu/activities/lulucf/>

Northern Eurasia Earth Science Partnership Initiative (NEESPI): <http://neespi.org/>

MARGINS project: <http://margins.ecoclimatology.com/index.html>

Expected climate change and options for EU silviculture (ECHOES): <http://www.forestry.gov.uk/website/forestresearch.nsf/ByUnique/INFD-7NBCPQ>

EU targets action on forests: <http://www.euractiv.com/sustainability/eu-targets-action-forests-news-299524>

EU Green Paper on forest protection and climate change: <http://www.euractiv.com/sustainability/eu-targets-action-forests-news-299524>

IPCC AR4: Forestry: http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch9.html

REFERENCES

- Alila, Y., Kuras, P. K., Schnorbus, M., and Hudson, R. (2009). Forests and floods: A new paradigm sheds light on age-old controversies. *Water Resources Research*, 45, W08416, doi:10.1029/2008WR007207.
- Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kizberger, T., et al. (2010). A global overview of drought and heat-induced tree mortality reveals emerging climate change risks of forests. *Forest Ecology and Management*, 259, 4, 660-684.
- Andréassian, V. (2004). Waters and forests: from historical controversy to scientific debate. *Journal of Hydrology*, 291, 1-27.
- Brown, A. E., Zhang, L., McMahon, T. A., Western, A. W., and Vertessy, R.A. (2005). A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *Journal of Hydrology*, 310, 28-61.
- Brown, T. C., Hobbins, M. T., and Ramirez, J. A. (2008). Spatial distribution of water supply in the coterminous United States. *Journal of the American Water Resources Association*, 44, 6, 1474-1487.
- Calder, I. R. (2002). Forests and hydrological services: reconciling public and science perceptions. *Land Use and Water Resources Research*, 2, 1-12.
- Drüszler, Á., Csirmaz, K., Vig, P., and Mika, J. (2010). Effects of documented land use changes on temperature and humidity regime in Hungary. In Saikia S. P. (Ed.), *Climate Change*. Int. Book Distr., Dehra Dun, Uttarakhand, India, 394-418.
- Ellison, D., N. Futter, M., and Bishop, K. (2011). On the forest cover-water yield debate: from demand- to supply-side thinking. *Global Change Biology*, doi: 10.1111/j.1365-2486.2011.02589.x.
- FAO (2010). Global Forest Resources Assessment 2010. Main report. FAO Forestry Paper 163, Rome
- Gálos, B., Jacob, D., and Mátyás, C. (2011). Effects of simulated forest cover change on projected climate change – a case study of Hungary. *Acta Silvatica et Lignaria Hungarica*, 7, 49-62.
- Greeff, L. (2010). Thirsty tree plantations, no water left and climate confusion: what version of sustainable development are we leaving our children? *EcoDoc Africa*, 39.
- Gribovszki, Z., Kalicz, P., Kucsara, M. (2006). Streamflow characteristics of two forested catchments in the Sopron Hills. *Acta Silv. Lign. Hung.*, 2: 81-92
- Hogg, E. H., and Price, D. T. (2000). Postulated feedbacks of deciduous forest phenology on seasonal climate patterns in the Western Canadian Interior. *Journal of Climate*, 13, 4229-4243.
- Ice, G. G., and Stednick, J. D. (2004). A century of forest and wildland watershed lessons. Society of American Foresters, Bethesda, Maryland. P287.
- Jackson, R. B., Jobbágy, E. B., Avissar, R., Roy, S. B., Barrett, D. J., Cook, C. J., et al. (2005). Trading water for carbon and with biological carbon sequestration. *Science*, 310, 1944-1947.
- Járó, Z. (1980). [Interception in man-made forest ecosystems in Gödöllő]. Erdészeti Kutatások (Budapest) 73: 7-17. (in Hungarian, with English summary)

- Jump, A., Mátyás, C., and Penuelas, J. (2009). The paradox of altitude-for-latitude comparisons in species' range retractions. *Trends in Ecology and Evolution*, 24, 12, 694-700.
- Law, B. E., Falge, E., Gu, L., Baldocchi, D. D., Bakwin, P., Berbigier, P., Davis, K., et al. (2002). Environmental controls over carbon dioxide and water vapor exchange of terrestrial vegetation. *Agricultural and Forest Meteorology*, 113, 97-120.
- Lu N., Wilske, B., Ni, J., John, R., and Chen J. (2009). Climate change in Inner Mongolia from 1955 through 2005. *Environmental Research Letters*, 4, 045006.
- Major, P. (2002). [Impact of lowland forests on water balance]. *Hidrológiai Közlöny (Budapest)* 82 (6): 319-324. (in Hungarian, with English summary)
- Malmer, A., Murdiyarso, D., Bruijnzeel, L. A., and Ilstedt, U. (2009). Carbon sequestration in tropical forests and water: a critical look at the basis for commonly used generalizations. *Global Change Biology*, 16, 1-6.
- Mátyás, C. (Ed.) (2010a). *Forests and Climate Change in Eastern Europe and Central Asia. Forests and Climate Change W. Pap. Nr. 8*, Rome, FAO, 189 p.
- Mátyás, C., Czimber, K. (2000): [Modeling zonal forest associations on the mesoclimatic level: possibilities for forecasting climate change effects] In: Tar, K. (ed): Proc., 3rd Conf. Forest and Climate, Debrecen University, 83-97 (in Hungarian, with English summary)
- Mátyás, C., Nagy, L., and Ujvári-Jármay, É. (2010). Genetically set response of trees to climatic change, with special regard to the xeric (retreating) limits. *Forstarchiv (Hannover)*, 81, 130-141.
- Mátyás, C., Sun, G., Zhang, Y. (2013) Afforestation and forests at the Dryland edges: lessons learned and future outlooks. In: *Dryland East Asia: Land dynamics amid social and climate change* (eds. Chen, J. Wan, S., Henebry, G., Qi, J., Gutman, G., Sun, G., Kappas, M.) Ecosystem Science and Applications, HEP Publishers, Beijing, and De Gruyter Publishers, 245-264
- Mátyás, C., Vendramin, G. G., and Fady, B. (2009). Forests at the limit: evolutionary-genetic consequences of environmental changes at the receding (xeric) edge of distribution. *Annals of Forest Science*, 66, 800-803.
- Móricz, N., Mátyás, C., Berki, I., Rasztovits, E., Vekerdy, Z., Gribovszki, Z., (2012). Comparative water balance study of forest and fallow plots. *iForest*, 5: 188-196
- Piao, S. L., Ciais, P., Huang, Y., Shen, Z. H., Peng, S. S., Li, J. S., et al. (2010). The impacts of climate change on water resources and agriculture in China. *Nature*, 467, 43-51.
- Qi J., Chen, J., Wan, S., and Ai, L. (2012). Understanding the coupled natural and human systems in Dryland East Asia. *Environmental Research Letters*, 7, 015202.
- Scott, D. F., Bruijnzeel, L. A., and Mackensen, J. (2005). The hydrologic and soil impacts of reforestation in the tropics. In M. Bonell and L.A. Bruijnzeel (Eds), *Forests, Water and People in the Humid Tropics*. Cambridge University Press, 622-651.
- Sun, G., Alstad, K., Chen, J., Chen, S., Ford, C. R., Lin, G., et al. (2011a). A general predictive model for estimating monthly ecosystem evapotranspiration. *Ecohydrology*, 4, 245-255.
- Sun, G., Caldwell, P., Noormets, A., Cohen, E., McNulty, S. G., Treasure, E., et al. (2011b). Upscaling Key Ecosystem Functions across the Conterminous United States by a Water-Centric Ecosystem Model. *Journal of Geophysical Research*, 116, G00J05, doi:10.1029/2010JG001573.
- Sun, G., Riekerk, H., and Kornak, L. V. (2000). Groundwater table rise after forest harvesting on cypress-pine flatwoods in Florida. *Wetlands*, 20, 1, 101-112.
- Sun, G., Zhou, G. Y., Zhang, Z. Q., Wei, X. H., McNulty, S. G., and Vose, J. M. (2006). Potential water yield reduction due to forestation across China. *Journal of Hydrology*, 328, 548-558.

- Szilágyi, J., Kovács, Á. and Józsa, J. (2012). Remote sensing based groundwater recharge estimates in the Danube-Tisza Sand Plateau region of Hungary, *J. Hydrol. Hydromech.*, 60, 2012, 1, 64-72
- Trabucco, A., Zomer, R. J., Bossio, D. A., van Straaten, O., and Verchot, L. V. (2008). Climate change mitigation through afforestation/reforestation: a global analysis of hydrologic impacts with four case studies. *Agricultural Ecosystems and Environment*, 126, 81-97.
- Wang, S., Fu, B., He, C.-S., Sun, G., and Gao, G.-Y. (2011). A comparative analysis of forest cover and catchment water yield relationships in northern China. *Forest Ecology and Management*, 262, 7, 1189-1198.
- Wang, Y., Yu, P., Feger, K.-H., Wei, X., Sun, G., Bonell, M., et al. (2011). Annual runoff and evapotranspiration of forest lands and non-forest lands in selected basins of the Loess Plateau of China. *Ecohydrology*, 4, 277-287.
- Wang, Y., Yu, P., Xiong, W., Shen, Z., Guo, M., Shi, Z., et al. (2008). Water yield reduction after afforestation and related processes in the semiarid Liupan Mountains, Northwest China. *Journal of the American Water Resources Association*, 44, 5, 1086-1097.
- Wei, X., Sun, G., Liu, S., Hong, J., Zhou, G., and Dai, L. (2008). The forest-streamflow relationship in China: a 40-year retrospect. *Journal of the American Water Resources Association*, 44, 5, 1076-1085.
- Xu, J. (2011). China's new forests aren't so green as they seem. *Nature*, 477, 371.
- Zhang, X. P., Zhang, L., McVicar, T. R., Van Niel, T. G., Li, L. T., Li, R., et al. (2008a). Modeling the impact of afforestation on mean annual stream flow in the Loess Plateau, China. *Hydrological Proceedings*, 22, 1996-2004.
- Zhang, X. P., Zhang, L., Shao, J., Rustomji, P., and Hairsine, P. (2008b). Responses of stream flow to changes in climate and land use/cover in the Loess Plateau, China. *Water Resources Research*, 44, W00A07, doi:10.1029/2007WR006711.
- Zhao, M. S., and Running, S. W. (2010). Drought induced reduction in global terrestrial net primary production from 2000 through 2009. *Science*, 329, 940-943.
- Zou, B. C., Ffolliott, P. F., and Wine, M. (2009). Stream flow responses to vegetation manipulations along a gradient of precipitation in the Colorado River Basin. *Forest Ecology and Management*, 259, 7, 1268-1276.

Forests in a changing climate

Imre Berki
Ervin Rasztoivts

ABSTRACT

This chapter provides quantitative information on the effect of climatic change on the distribution, growth, health and vitality of forests. In the analyses European beech is selected as indicator species. Although it is considered in its optimum highly plastic and adaptable, it becomes climate-sensitive closer to its xeric (lower) distribution limits. The future of beech in Southeast Europe requires special attention because this region harbours significant populations living at or near their xeric distribution boundary. Even though the low elevation occurrences are uniquely vulnerable to climatic shifts, observations and modelling studies pertaining to this region are particularly scarce.

Out of climatic factors determining the xeric distributional limits for beech, Ellenberg's drought index (EQ) appeared as the most influential. Growth response analyses in comparative tests have confirmed the existence of macroclimatic adaptation of beech and have proven that warming and more arid conditions lead to decline of growth and vitality, while no decline was observed if EQ changed in the opposite direction. The response to weather extremes was investigated in field plots. Recurrent summer droughts of 3 to 4 consecutive years, above mean EQ value 40-42 resulted in pest and disease attacks and mass mortality.

The discussed approaches indicate consistently a high level of uncertainty regarding the future of beech at the xeric limit in Southeast Europe. According to field observations and bioclimatic data in Hungary, a large part of low-elevation beech forests presently in the zone of EQindex ≥ 20 might be threatened by the warming in the second half of the century, while higher-elevation occurrences

may remain stable. The interpretation of the results bears some stipulations, such as the consequence of ecological and human interactions in influencing present distribution patterns, the unclear role of persistence, natural selection and plasticity and uncertainties of climate projections. Grim projections may probably be partly overwritten by the mentioned stipulations and by careful and prudent human support.

1 CHANGES IN CLIMATE CONDITIONS WITH RESPECT TO FOREST ECOLOGY

Adaptation strategy of forest trees is receiving growing attention in view of expected climatic changes. Scarcity of reliable information on responses to macroclimatic changes is a central problem and obstacle of planning for the future. In order to formulate realistic predictions, both the nature of adaptation to past and current climate, and the level of sensitivity to sudden environmental changes have to be understood and properly interpreted. The distribution of European beech extends across ecologically and climatically variable regions. Compared to other wide-spread tree species of Europe, it is still the one which was left in a relatively natural condition as – although in a distributional range reduced by man – it was seldom regenerated artificially and its reproductive material was not subject to large-scale commercial relocations such as oaks or Scots pine. Thus, present populations of European beech are still close to a „wild state“. Therefore beech is a well suited model species to study adaptation strategy of long-living, deciduous climax species to climate and to changes of climate. The species is considered climate-sensitive and vulnerable to changes. Therefore its response to predicted large-scale changes of climate is a critical issue.

In this study an attempt is presented to trace, quantify and project the impacts of macroclimatic change on the distribution and vitality of beech, with results interpretable for the practice, as such information is urgently needed to develop adaptation strategies for both forestry and conservation. Investigations were concentrated to the xeric limits in SE Europe. This region, where the retreat of the species is imminent, has been largely neglected by European studies (Jump et al. 2009, Mátyás et al. 2010). We consider the detailed, practice-oriented investigation of climate impacts at the xeric limits of primary importance because especially the low elevation occurrences of beech in the region are uniquely vulnerable to climatic shifts (Mátyás et al. 2010).

1.1 The threat to xeric limits in SE Europe

Xeric (or rear, trailing) limits at the low latitude and low altitude end of distribution ranges are determined by climatic aridity (Mátyás et al. 2009). At the xeric limit ecosystems are dependent on a volatile minimum of rainfall and are therefore sensitive to prolonged droughts. Even minor changes of temperature affect disproportionately larger tracts on plains as compared to mountainous regions. Presuming a spontaneous migration speed for beech of approx. 20 km/century (Davis 1981, Mátyás 2007) an increase of temperature of just 1°C would imply for beech a horizontal migration time of 750 years to follow the change. This fact explains the much larger vulnerability of low elevation occurrences in Southeast Europe.

According to calculations of the IPCC (Christensen et al. 2007), predicted temperature changes of the critical summer climate at the end of the century are much milder in North Europe between latitude 50° and 70° N, as compared to South Europe between 50° and 30° N. Table 1 shows that changes are more extreme in summer than those of annual averages. Drought projections for Southern Europe are also serious, while none are predicted for North Europe.

Table 1. Predicted annual and summer climate changes for the period 2080-2099 vs. the reference period of 1980-1999, according to the A1B scenario (data from the IPCC, Christensen et al. 2007)

	mean annual temperature dT (°C)	mean summer temperature dT (°C)	Change of mean annual precipitation dP (%)	mean summer precipitation dP (%)	percentage of dry summers (%)
South Europe, Mediterranean	+3.5	+4.1	- 12	- 24	42
North Europe	+3.2	+2.7	+ 9	+ 2	0

The expected drought frequency was separately modelled by us for the Carpathian Basin due to the importance of this climate factor (Gáloset al. 2007). The results of the projection, using the regional climate model REMO developed by the Max Planck Institute for Meteorology (Hamburg) indicate a very similar outcome: in the second half of the 21st century every second year could bring major summer drought events

(Table 2). Projected summer precipitation change is of special significance at the xeric limits which may affect profoundly the available climatic niche of dominant forest species, such as beech. This justifies the separate treatment of the Southeast European region.

Table 2. Frequency of recent and projected drought events for Hungary, according to scenario A1B, calculated with MPI's REMO regional climate model. Reference period: 1961–1990 (Gálos et al. 2007)

Period	Drought summers		
	number of years (out of 50 years)	mean of precipitation anomalies (%)	mean of temperature anomalies (°C)
1951–2000	15	–28.0	+0.9
2001–2050	17	–19.8	+1.5
2051–2100	26	–37.6	+4.2

1.2 Climatic factors of the xeric distributional limits for beech in SE Europe

The actual climatic envelope (niche) of beech has been repeatedly modelled (e.g. Kölling 2007, Bolte et al. 2007, Kramer et al. 2010). However, the studies focus on continental-scale effects of climate change, using low resolution climatic and species distribution data. To identify the limiting macroclimatic factors at the xeric distributional limits of beech forests a regional modelling analysis was carried out in Hungary (Czúcz et al. 2011). Out of the basic set of climatic variables late spring (May) temperature (T_{05}) appeared as the most influential predictor. In addition, annual precipitation (P_a) also played a significant role in determining the presence of beech near its xeric limit (Czúcz et al. 2011).

The probability of presence of beech was modelled by the variables seasonal and monthly temperature and precipitation means, interpolated for the grid cells. In addition Ellenberg's climate quotient (EQ, Ellenberg, 1988) was also applied, defined as the mean temperature of the warmest month (July, T_{07}) divided by annual precipitation (P_a):

$$EQ = 1000 (T_{07} / P_a)$$

Ellenberg's climate quotient is a simple index expressing the joint effect of temperature and precipitation, and it has been generally used to express humidity conditions in Central Europe.

It is obvious that when modelling the probability of presence of beech, neither temperature nor precipitation can be considered as a single factor. EQ index seems to characterise the climate conditions for beech in the region reliably and will be used for analysing responses to changing conditions in the followings.

2 GROWTH RESPONSE TO CHANGING CLIMATIC CONDITIONS

The growth response (or transfer) analysis of the SE European beech trials yielded the following main conclusions (Mátyás et al. 2010):

- a climate-dependent component of adaptive genetic response could be identified
- across populations of different origin, i.e. adaptation to (and consequently, selection effect of) macroclimate exists in beech in spite of counteracting evolutionary and ecological effects;
- the change of climatic conditions toward warming and more arid conditions lead to decreasing height growth and vitality, while vitality is not affected if changes happen in the opposite direction.

3 RESPONSE TO WEATHER EXTREMES

Effects of climatic change are described as shifts of vegetation zones, realised through "migration" of species. In case of forest trees, "migration" means loss of competitive potential and subsequent decline of vitality followed by pestand disease attack. However, the response of forests to drought – contrary to grass or crop vegetation – is not immediate. Forest stands, even drought-sensitive beech, survive single extreme summers and recover merely with yield loss. This is the result of deep rooting of trees, utilizing deeper soil water resources. The situation is different if drought years happen consecutively.

In the literature “mortality syndrome” (Worrall et al. 2008) cases have mostly been treated as isolated, transient problems related to extreme events, rather than as a consequence of a long-term climate shift. This is because the gradual, relatively slow change of climatic means does not express the current effect of extremes at the xeric limits. Spontaneous climatic selection is driven by recurrent drought events and the symptoms of change appear usually quite abruptly. Climatic means in models should be regarded therefore rather as surrogates for extreme events. The long-term, gradual shift of climatic factors has merely predisposing role. Besides climate, the site conditions, age and structure of stand play also a predisposing role. Inciting factors are mainly connected to climatic anomalies especially at the xeric limits. Pests or diseases attacking populations of weakened vitality are then the direct or proximate causes of mortality.

3.1 Health and vitality loss due to climatic extremes: case study of beech in SW Hungary

The gradually growing moisture deficit in Hungary has led to health problems in Hungarian beech forests since the 1990s, first of all in the Southwest of the country where climatic changes were the strongest, and where the stands are at low elevation and close to the xeric limits. The weakened trees became more sensitive to secondary pests and pathogens and showed symptoms of health deterioration (early leaf abscission, sparser crowns, etc.). The extent of climate damages of the drought years 2000–2004 has been investigated in two West Hungarian state forest companies. In 460 damaged forest compartments (total area: 3900 ha) 87.7 thousand cu.m. of damaged timber was harvested. The damaged stands were mostly above 60 years (T. Szép, unpubl. data). The area most damaged was the Zalaegerszeg forest district (Zala county), where mass mortality was triggered in mature beech stands after regeneration cuts, when the canopy closure was opened up. This led to the outbreak of the otherwise harmless beech buprestid (*Agrilus viridis*). Damage of *Biscogniauxia nummularia* disease and of the beech bark beetle (*Taphrorychus bicolor*) occurred together with the buprestid damage. As a consequence close to 70,000 cu.m. of sanitary felling had to be executed in 2005 in that forestry district alone (Figure 1, Lakatos–Molnár 2009). The type of damage supports the observation of forest protection experts that disturbance of the closed canopy increases the risk of climate damage.



Figure 1. Symptoms of beech decline in 2004 in Zala county, following the damage of *Taphrochus bicolor* on the trunk (Molnár – Lakatos 2009)

3.2 Analysis of drought events

For the closer definition of extreme weather effects leading to the “mortality syndrome” in beech, threatened stands have been selected in different parts of the country. For the analysis on annual basis, EQ had to be modified to be suitable to characterise individual years’ weather. Mean temperature of the 3 summer months was used for the annual EQ index instead of just July’s, to avoid random effects of individual months (in case of 30-year climate averages, this is not a problem). Investigation of mortality frequency has shown that single drought events did not threaten the stability of populations. The recurrent drought period lasting up to five years in some areas, has however resulted in very serious mortality in the investigated beech stands, in one case the population went extinct (Figure 2).

As an example, effects of consecutive drought events are shown for a South Hungarian beech forest at the xeric limits of distribution. The stand has been selected at the edge of the xeric limit which is indicated by the frequency of droughty years. Years with EQ indices significantly above 30 have been considered as drought events. Mass mortality started in 2003, in the fourth year of consecutive drought, after an extremely dry summer. Observations at other locations have confirmed that in case of beech, recurrent drought events of 3 to 4 consecutive years (depending on severity) lead in general to irreversible mass mortality and local extinction (Berki et al. 2009). It was

also found that not only the number of consecutive years, but the severity of drought period has an influence on the decline. Data of selected observation plots near the xeric limit (Figure 3) confirm a direct, causal link between health and drought. Mean summer drought severity above EQ value 40–42 seem to trigger a mass mortality syndrome.

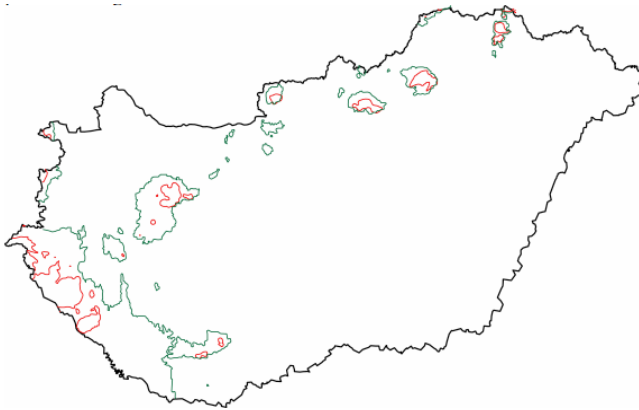


Figure 2. Shrinking of the climatic xeric limit of beech (EQ = 29) in Hungary between the beginning of the 20th century (1900-1930, green) and for the period 1975-2004 (red). (design: E. Rasztoivits)

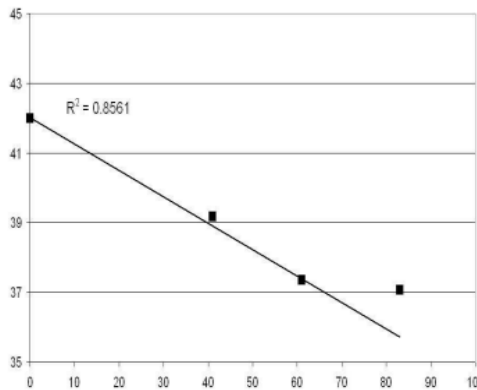


Figure 3. Average EQ value of the drought years 2000-2004 (vertical axis) and the health condition of selected mature beech plots at the xeric limit, at the end of the period (percentage of healthy individuals, horizontal axis) (unpublished data of Berki and Móricz)

4 PROJECTIONS FOR THE FUTURE

How exactly xeric limits of beech will shift in the future is poorly explained by currently available models. For predicting future distribution of beech on the basis of bioclimatic models, climatic projections of the Intergovernmental Panel on Climate Change (IPCC, Christensen et al. 2007) were applied (Table 3).

Table 3. Expected changes of climatic conditions by 2050 and estimated climatic space of zonal beech (Δ beech) forest stands in Hungary. Projected changes in summer half year temperature (Δ Ts °C) and precipitation (Δ Ps, percents) are shown for six IPCC AR4 climatic scenarios (extracted from Czúcz et al.2011)

	HADCM3 A2	HADCM3 A1B	HADCM3 B1	CNCM3 A2	CSMK3 A2	GFCM21 A2
Δ Ts	+2.9	+3.3	+2.6	+2.4	+1.8	+2.1
Δ Ps (%)	-13.4	-10.9	-12.4	-9.6	+0.4	-11.4
Δ beech (%)	97-99	94-99	97-99	97-99	56-96	92-99

Table 3 reveals surprisingly high levels of range reduction, relatively independently from applied scenario projections. The projected potential distributions indicate a drastic reduction in macroclimatically suitable sites for beech, as 56–99% of present-day zonal beech forests might be outside their optimal bioclimatic niche by 2050. However, the projections of analysis only pertain to zonal beech forests in plachor position and other uncertainties of the projections are also high (Czúcz et al. 2011).

Climatic changes will result in relatively homogeneous shifts in EQ values throughout the SE European distributional range of beech. Using the projected statistics of IPCC for Southern Europe (partly presented in Table 1), the climatic shift until 2080 was calculated as +11 Δ EQ. This suggests that – using the distribution limit value of 29 EQ – at locations with present EQ values below 29 – 11 \approx 18–20 EQ, beech may survive, even if under stress. The larger part of the distributional range, especially Atlantic NW Europe as well as the higher elevation occurrences of the continental mountains (e.g. the Carpathians or the Balkan Range), fall into this group.

On the contrary, at the low-elevation xeric limits EQ would rise in 2080 from 29 to 40 EQ. Theoretically, part of these populations could survive as well, assuming that mass mortality starts only if the difference from the originally adapted climate surpasses +13 Δ EQ as stated above – if no extreme events and subsequent pests, epidemics occur in this time period. This assumption seems rather unrealistic. It has to be emphasized that all modelled responses were measured within the present distribution range of beech; there is no test site outside the xeric limits (which is a deplorable, but understandable drawback of the provenance test series). It is therefore impossible to formulate a more realistic estimate based on transfer analysis for the locations close to the limits.

4.1 Responses validated by field observations

The future frequency of drought events has been analysed for the territory of Hungary. The projected frequency of drought summers (precipitation decline exceeding 15% of the seasonal mean) were calculated with MPI's REMO regional climate model (Figure 9). It is highly remarkable that from 2050 onward, the model projects at least one occasion per decade when 3 or more consecutive years with drought summers will happen, while only three such periods are projected for the first half of the century. Although droughts hit usually regionally, the predicted drought frequency may have an impact on the most part of the investigated beech area at least once during the century. The close link between extreme events and pest outbreaks exacerbate the expected damages. Drought will have its effect also on natural regeneration of stands as well (Czajkowski et al. 2005). These results support the grim outcome of the bioclimatic forecast for the second half of the century.

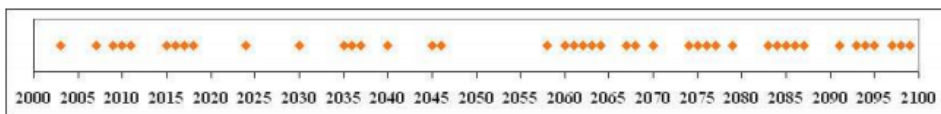


Figure 4. Frequency of consecutive drought events for Hungary, according to scenario A1B, based on results of the REMO model. Symbols depict years of droughty summers (Gálos et al. 2007)

Concluding, the outcome of the projections indicates a high level of uncertainty regarding the future of beech in Southeast Europe. **According to the bioclimate approach 56–99% of present-day zonal beech forests might be outside their optimal climatic niche by 2050 (figure 5). The extrapolations of field observations on “drought plots” at the xeric limit also point toward a nearly complete loss of all beech stands in course of the century.**

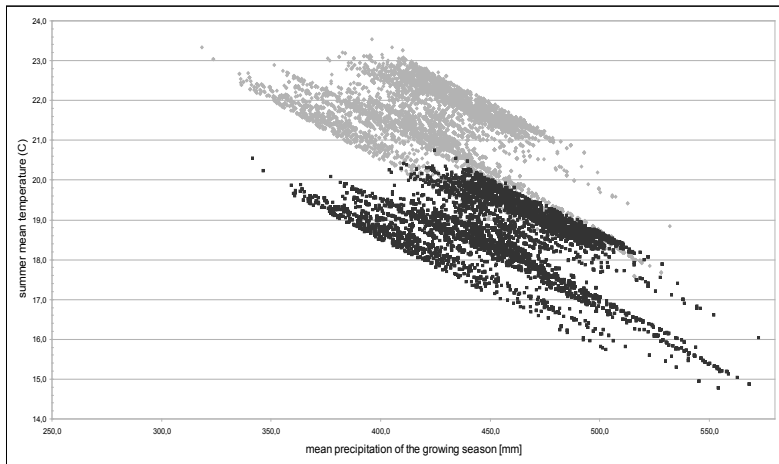


Figure 5. Climate parameters (mean precipitation of the growing season vs. mean summer temperature) of actual beech occurrences in Hungary (black) and parameters calculated for the climate conditions in 2050 (grey) (data by E. Rasztoivits)

5 FINAL CONCLUSIONS

Summing it up, projections into the far future may be biased by a number of uncertainties. Taking the ensemble of deductions of current, fairly deviating projections for granted, the comparison of very different approaches confirm the probability of serious climate impacts on distribution, health and productivity of beech. These effects will appear nonetheless differentiated, according to the ecological and genetic status of local beech occurrences. It is also important to note that contrary to mortality events and health decline along the xeric limits of the species, “compensatory” colonisation at the thermic (or front) limits, as projected by ecological models, will not happen spontaneously because of human obstacles to

colonisation and due to the fairly low migration speed of beech compared to other deciduous species (Davis 1981, Mátyás 2009, Jump et al. 2009).

Observations of mortality events close to the lower (xeric) limit of the species indicate that **stability and vitality of populations depend not only on shifts in climatic means. Extreme weather events (droughts) may weaken physiological condition of populations relatively fast and may lead to insect and disease outbreaks also in regions generally suitable for the species.** The shrinking of future distribution of beech as suggested by various bioclimatic models (e.g. Thuiller et al. 2005, Czúcz et al. 2011) represent probably pessimistic scenarios which may be alleviated not only by the mentioned features but also by prudent human support (e.g. artificial regeneration and other silvicultural measures, see Mátyás 2010). In the major part of the range the predicted changes will not trigger any decline due to the plasticity of the species: the predicted “decoupling” is improbable (Jump, Penuelas 2005). It would be however misleading to expect the same level of persistence and plasticity at the threatened xeric limits as across the rest of the range.

Therefore the forecasts have to be taken serious close to the xeric limits, and especially at low elevations. Field observations near the retracting distributional limits confirm that the decline process is ongoing in many locations (Penuelas et al. 2007, Berki et al. 2009). Considering the rapid shrinking of suitable bioclimatic space and the increasing selection pressure of abiotic and biotic stressors at the xeric limits, the results underline the importance of adaptive strategies both for management and conservation of forest resources. This calls also for relevant, well designed field studies and further development of prediction methods and modelling (Mátyás 2010).

The results of this study may contribute to the adjustment of adaptation and mitigation policy in forestry and nature conservation, to the revision of rules for deployment of reproductive material and also to validating evolutionary and ecological hypotheses related to climate change effects.

5.1 Related websites, projects and videos

Forest cover maps, forest type maps for Europe:

<http://forest.jrc.ec.europa.eu/activities/forest-mapping/>

<http://forest.jrc.ec.europa.eu/efdac/applications/viewer/>

http://www.euforgen.org/distribution_maps.html

forests and climate change (on maps): <http://forest.jrc.ec.europa.eu/activities/climate-change/>

climate change impacts on forestry: <http://www.forestry.gov.uk/fr/INFD-5Y2HR7>

IPCC AR4: Forestry: http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch9.html

REFERENCES

- Berki, I. – Rasztoivits, E. – Móricz, N. – Mátyás, C. (2009): Determination of the drought tolerance limit of beech forests and forecasting their future distribution in Hungary. *Cereal Research Communications*, 37: 613–616.
- Bolte, A. – Czajkowski, T. – Kompa, T. (2007): The north-eastern distribution range of European beech – a review. *Forestry*, 80 (4): 413–429.
- Christensen, J.H. – Hewitson, B. – Busuioc, A. – Chen, A. – Gao, X. – Held, I. et al. (2007): Regional Climate Projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. & Miller, H.L. (eds) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK. 747–845.
- Czajkowski, T. – Kuhling M. – Bolte A. (2005): Einfluss der Sommertrockenheit im Jahre 2003 auf das Wachstum von Naturverjüngungen der Buche (*Fagus sylvatica* L.) im nordöstlichen Mitteleuropa, *Allg. Forst- u. Jagdztg.* 176: 133–143.
- Czúcz B., Gálhidy L. & Mátyás C. (2011). Present and forecasted xeric climatic limits of beech and sessile oak distribution at low altitudes in Central Europe. *Ann. For. Sci.*, 68(1), 99-108
- Davis, M. (1981): Quaternary history and stability of forest communities. In: West, D.C., et al. (ed.): *Forest succession: concept and application*. Springer, New York, 132–153
- Ellenberg, H. (1988): *Vegetation ecology of Central Europe*, 4th ed., Cambridge University Press
- Gálos, B. – Lorenz, Ph. – Jacob, D. (2007): Will dry events occur more often in Hungary in the future? *Env. Res. Letters*, 2: 034006 (9pp) doi: 10.1088/1748-9326/2/3/034006
- Jump, A.S. – Peñuelas, J. (2005): Running to stand still: adaptation and the response of plants to rapid climate change. *Ecology Lett.* 8: 1010–1020
- Jump, A. – Mátyás, C. – Peñuelas, J. (2009): The paradox of altitude for latitude comparisons in species range retractions. (Review) *Trends in Ecology and Evolution*, 24: 12, 694–700, doi: 10.1016/j.tree.2009.06.007
- Kölling, C. (2007): Klimahüllen von 27 Waldbaumarten. *AFZ - der Wald*, 23: 1242–1244
- Kramer, K. – Degen, B. – Buschbom, J. – Hickler, T. – Thuiller, W. – Sykes, M. – De Winter, W. (2010): Modelling exploration of the future of European beech (*Fagus sylvatica* L.) under climate change – Range, abundance, genetic diversity and adaptive response. *For. Ecol. Managem.*, 259: 2213–2222.
- Lakatos, F. – Molnár, M. (2009): Mass mortality of beech on Southwest Hungary. *Acta Silvatica & Lignaria Hung.*, 5: 75–82
- Mátyás, C. (2007): What do field trials tell about the future use of forest reproductive material? In: Koskela, J., Buck, A., Teissier DU Cros, E. (eds.): *Climate change and forest genetic diversity:*

- Implications for sustainable forest management in Europe. Bioersivity International, Rome, 53–69
- Mátyás, C. (2009): Ecological challenges of climate change in Europe's continental, droughtth-reaterened Southeast. In: Groisman, P.Y. –Ivanov S.V. (eds.): Regional aspects of climateter-restrial-hydrologic interactions in non-boreal Eastern Europe. NATO Science Series, Springer Verl., 35–46
- Mátyás C. (2010): Forecasts needed for retreating forests (Opinion) *Nature*, 464: Apr. 29, 1271
- Mátyás, C. – VENDRAMIN, G. – FADY, B. (2009): Forests at the limit: evolutionary-genetic consequences of environmental changes at the receding (xeric) edge of distribution. *Ann. of Forest Sci.*, 66: 800–803
- Mátyás C., Berki I., Czúcz B., Gálos B., Móricz N. & Rasztovits E. (2010). Future of beech in Southeast Europe from the perspective of evolutionary ecology. *Acta Silv. & Lign. Hung.*, 6, 91-110
- Thuiller, W. – Richardson, D.M. – Pyšek, P. – Midgley, G.F. – Hughes, G.O. – Rouget, M. (2005): Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. *Global Change Biol.* 11: 2234–2250
- Worral, J.J. – Egeland, L. – Eager, T. – Mask, R.A. – Johnson, E.W. – Kemp, P.A. – Shepperd, W.D. (2008): Rapid mortality of *Populus tremuloides* in Southwestern Colorado, USA. *For. Ecol. Managem.*, 255: 686–696

Afforestation for Restoration of Land and Climate Change Mitigation, Part 3.

Structure and functioning of forest ecosystems

Attila Eredics
Norbert Móricz
András Bidló
Csaba Mátyás

1 FOREST MICROCLIMATE AND MICROCLIMATE MEASURING TECHNIQUES

1.1 Introduction

Microclimatology is the study of climate on a small scale, as of a city, a valley, but even a hole in the tree trunk has its own microclimate. The microclimate of the forest is one of the most complicated amongst other land cover forms. The reasons for complexity are the levelled structure, the annual variability and the fact that not only the climate influences the forest, but the forest also affects its own microclimate. This dynamic feedback makes the description and modelling of the forest microclimate more difficult. Proper understanding of the main micrometeorological processes is vital for effective forest planning and management. Thus firstly we will cover the basics of micrometeorology, the structure of the boundary layer and the exchange of energy and water. Typical microclimatological situations such as land-sea and mountain-valley circulations and local cold airflows are analysed. Forests have a certain vertical structure, which further complicates the processes. During the vegetation period the canopy is the active surface for the energy transformation, and the trunk space may have highly different microclimate depending on the horizontal structure. By changing the density and distribution of the canopy, forest managers have a flexible tool for helping regeneration and the growth of seedlings. Lastly basic microclimatological measurement techniques are discussed.

1.2 Syllabus

1.2.1 Micrometeorology

Chapter 1.1 (pp. 1-4) in Foken (2008): Micrometeorology

a) Atmospheric scales

Chapter 1.2 (pp. 4-5) in Foken (2008): Micrometeorology

b) Atmospheric boundary layer

Chapter 1.3 (pp. 6-8) in Foken (2008): Micrometeorology

c) Energy balance

Chapter 1.4 (pp. 8-23) in Foken (2008): Micrometeorology

d) Water balance

Chapter 1.5 (pp. 23-24) in Foken (2008): Micrometeorology

1.2.2 Basics of microclimatology

a) Climatological scales

Chapter 7.1 (pp. 223-224) in Thomas Foken (2008): Micrometeorology

b) Small scale changes of climate elements

Chapter 7.2 (pp. 224-225) in Foken (2008): Micrometeorology

c) Typical microclimatic circulations

Chapter 7.3 & 7.4 (pp. 226-230) in Foken (2008): Micrometeorology

1.2.3 Forest Microclimate

a) Vertical structure of the forest

Parker (1995): Structure and microclimate of forest canopies

b) Horizontal microclimate gradients

Davies-Colley et al. (2000): Microclimate gradients across a forest edge

c) Effects of different management regimes

Chen et al. (1999): Microclimate in Forest Ecosystem and Landscape Ecology

Zheng et al. (2000): Effects of silvicultural treatments on summer forest microclimate in southeastern Missouri Ozarks

1.2.4 Microclimate measuring techniques

Chapter 7.5 (p. 231) in Foken (2008): Micrometeorology

a) Radiation

Chapter 6.2.1 (pp. 189-193) in Foken (2008): Micrometeorology

b) Wind

Chapter 6.2.2 (pp. 193-200) in Foken (2008): Micrometeorology

c) Temperature and humidity

Chapter 6.2.3 (pp. 200-208) in Foken (2008): Micrometeorology

d) Precipitation

Chapter 6.2.4 (pp. 208-209) in Foken (2008): Micrometeorology

1.2.5 Instruments, equipments

(sources of pictures: www.fernbank.edu, <http://www.eol.ucar.edu/projects/ceop/dm/insitu/sites/baltex/lindenberg/forest/>)



Figure 1 and 2: Forest tower



Figure 3. Anemometer and Wind Vane at 42 meters



Figure 4. Temperature & Relative Humidity (left), rain (center) Solar Radiation (right) at 42 meters



Figure 5. Anemometer and Wind Vane at 21 meters



Figure 6. Anemometer and Wind Vane at 10 meters



Figure 7. Under the Canopy Tipping Bucket Rain Guage



Figure 8. Temperature & Rel Humidity Cover (center) Solar Radiation (left) at 21 meters



Figure 9-10. Throughfall and stemflow measurements

RELATED WEBSITES, PROJECTS AND VIDEOS

forest ecosystem services:

<http://forest.jrc.ec.europa.eu/activities/forest-ecosystem-services/>

<http://www.youtube.com/watch?v=-FVlvWjJeTQ>

International Network Measuring Terrestrial Carbon, Water and Energy Fluxes (FLUXNET):

<http://www.ileaps.org/?q=node/66>

forest microclimate research:

<http://www.safeproject.net/projects/earth-atmosphere-linkages/microclimate/microclimate-stratification-in-modified-forests/>

http://www.serc.si.edu/labs/forest_ecology/microclimate.aspx

http://www.wsl.ch/fe/walddynamik/projekte/BelCanClim/index_EN

<http://www.youtube.com/watch?v=hqVig0B5UOg>

REFERENCES

Chen, J., Saunders, S. C., Crow, T. R., Naiman, R. J., Brosofske, K. D., Mroz, G. D., Brookshire, B. L., Franklin, J. F. (1999): Microclimate in Forest Ecosystem and Landscape Ecology. (Variations in local climate can be used to monitor and compare the effects of different management regimes) *BioScience* Vol. 49 No. 4.

Davies-Colley, R. J., Payne, G. W., Elswijk, M. (2000): Microclimate gradients across a forest edge. *New Zealand Journal of Ecology* (2000) 24(2):111-121.

Foken, T. (2008): *Micrometeorology*. Springer-Verlag Berlin Heidelberg. ISBN: 978-3-540-74665-2 e-ISBN: 978-3-540-74666-9

Parker, G. G. (1995): Structure and microclimate of forest canopies. Chapter 4 in Lowman, M.D. and Nadkarni, N.M. (eds.) 1995. Forest Canopies. Academic Press 624 pp.

Zheng, D., Chen, J., Song, B., Xu, M., Sneed, P., Jensen, R. (2000): Effects of silvicultural treatments on summer forest microclimate in southeastern Missouri Ozarks. Climate Research Vol. 15: 45-59.

The resources in digital format:

Chen_(1999)_Microclimate_in_forest_ecosystem.pdf

Davies-Colley_(2000)_Microclimate_gradients_across_a_forest_edge.pdf

Foken_(2008)_Micrometeorology_Chapter_1.1-1.5.pdf

Foken_(2008)_Micrometeorology_Chapter_6.2.1-6.2.4.pdf

Foken_(2008)_Micrometeorology_Chapter_7.1-7.5.pdf

Parker_(1995)_Structure_and_microclimate_of_forest_canopies.pdf

Zheng_(2000)_Effects_of_sylvicultural_treatments.pdf

2 ROLE OF FOREST COVER IN THE HYDROLOGICAL CYCLE - CASE STUDY OF MEASUREMENTS AND MODELLING

2.1 Introduction

Land-atmosphere interactions related to the energy and water cycle are linked by the processes of evapotranspiration. Evapotranspiration is a collective term for all the processes, by which water in the liquid or solid phase at or near the earth's land surfaces becomes atmospheric water vapour (Dingman 2002). It is the sum of transpiration, interception, bare soil evaporation and evaporation from open water and snow.

Transpiration is the vaporization of water from the saturated interior surfaces of leaves to the surrounding air via microscopic pores called stomata (Hungate and Koch 2003). Stomata open and close in response to environmental factors such as light,

temperature, CO₂ concentration and soil water. Interception is the part of the rainfall, which evaporates from the vegetation during and after the precipitation event. Bare soil evaporation is the vaporization of water directly from the mineral soil surface. It is only a small amount under forests because of the litter on the ground (Hewlett 1982).

Vegetation is basically influencing the water budget through interception and transpiration, which are affected by the leaf area and the rooting depth of the plants.

Leaf area index (LAI) is defined as a one sided green leaf area per unit ground area (Bonan 2008). It affects the radiative transfer process within the canopy and evapotranspiration from the plant surface. LAI varies temporally with age and phenology. Its value differs strongly among plant communities. Measurements by Járó (1959) showed the large variability of LAI (from 2.5 to 8.4) in different Hungarian forest types depending on age and site conditions.

Forests have larger leaf area compared to other vegetated surfaces. Larger LAI warms the surface due to lower albedo. But larger LAI also results in larger roughness length thus higher evapotranspiration rate in forests (Betts et al. 1997), which influences the exchange of both latent and sensible heat fluxes. The increase of the latent heat flux through transpiration is the major contributor to the cooling of the surface. The process is called evaporative cooling effect, which is the other basic biogeophysical feedback of forests on climate. It dominates primarily on the tropical regions leading to cooler and moister atmospheric boundary layer that may feed back to increased precipitation by affecting the larger-scale circulation (Brovkin 2002, Kleidon et al. 2007).

Vertical profile of leaf area in the forest canopy affects the distribution of radiation in the canopy. Larger leaf area increase the canopy shading, which leads to cooler air temperatures in the stem area, decrease of net radiation at the soil surface, therefore less bare soil evaporation in summer (Pitman 2003, Chang 2006).

Due to the higher evaporation rate, forests may increase the amount of precipitation. Chang (2006) summarizes the arguments and counterarguments to the possible precipitation-increasing role of forests. It is often assumed that forests enhance the precipitation formation increasing the effective height of mountains, which leads to an increase of the orographic precipitation. The higher transpiration rate of forests can lead to the increased vapour content of the air, which promotes the condensation and precipitation formation in the forested area. The basic counterargument is that

the horizontal distribution of precipitation is mainly affected by the general circulation and topographic characteristics rather than by forests. For the precipitation formation water vapour content is not enough (Chang 2006).

The amount of precipitation, which reaches the ground surface infiltrates into the soil. Rooting depth and the soil texture determine the amount of water that can be stored in the soil, which is potentially available to the vegetation for transpiration (Kleidon and Heimann 1998). Available water holding capacity can be defined as the difference between field capacity (the amount of water after gravitational drainage) and wilting point (the amount of water in the soil when evapotranspiration ceases; Bonan 2004). Rooting depths have a large variability depending on plant species soil texture and soil water conditions.

Deep roots increase the water uptake and the amount of transpiration. It is an important characteristic in dry spells when moisture of advective origin diminishes. If there is enough moisture in the soil to continue evapotranspiration, local evapotranspiration can be an important contributor to precipitation.

2.2 Case study: Comparative Water Balance Study of Forest and Fallow Plots

2.2.1 Background

The relationship of vegetation cover and groundwater resources has drawn considerable scientific attention over the last decades. Many studies have shown that deforestation by logging or of natural origin (forest fire, wind damage) increased the average runoff from the affected area (e.g. Bosch & Hewlett 1982) and afforestation decreased runoff. Similar results were detected in recharge rates and groundwater depth, predominantly in dry regions. In Australia changes of vegetation from woodland to grassland or crops resulted in increases in recharge rates of one to two orders of magnitude (Maitre et al. 1999). The changes were largely due to the altered interception loss and the increased water extraction from the root zone. However, results of paired watershed research agreed only on the direction of the changes, not on their magnitude (Andressian 2004).

Comparative water balance studies of forest and low vegetation covers have generally shown higher water use of forest cover (Nachabe et al. 2005, Schilling 2007). Nachabe et al. (2005) analysed the groundwater consumption in a shallow water table environment and estimated the annual ET for a forested area (1320 mm) and for a pasture (700 mm) using detailed soil moisture and water table monitoring. At the same time, a few studies have found negligible differences in evapotranspiration of different vegetation covers (e.g. Roberts & Rosier 2005). The latter study found that, although there were seasonal differences, on an annual basis, the drainage below broadleaved woodland did not significantly differ from that below a pasture.

Due to climate change, air temperature is expected to rise significantly during this century (IPCC 2007). As a direct consequence of warmer temperatures, the hydrologic cycle will undergo changes with accompanying alteration in the rates of precipitation and evaporation. In Hungary, summer temperatures may increase by up to four degrees by the end of this century, while precipitation is likely to increase in winter and decrease in summer (Gálos et al. 2007).

The impact of climate change on groundwater resources was reviewed lately by Green et al. (2011). Although the uncertainty of predictions for change in groundwater recharge rates and discharge is large (e.g. future climate scenarios and groundwater extraction), numerous studies found that groundwater resources appear to be threatened by future climate change due to increased natural and human water demand.

In light of the water balance uncertainties and the increasing pressures on groundwater resources due to future climate change, a comparative water balance study of an oak forest and fallow vegetation plots was initiated in a drought-threatened lowland environment in Northeastern Hungary. Water balance components were estimated by the Hydrus 1-D numerical model (Simunek et al. 2005), calibrated on measured soil moisture and groundwater levels.

2.2.2 Materials and methods

Study area

The study plots are situated in the Northeast part of Hungary at latitude 47° 58' N and longitude 21° 42' E (Fig. 11), built up from sandy river deposits of the early Pleistocene (Borsy et al. 1981). The climate is continental; the mean annual precipitation (1951-

2000) is approximately 520 mm and mean monthly temperature (1951-2000) ranges between -2.4°C in January and 20.5°C in July.



Figure 11. Location of the study area

The plots were located on the discharge area of the local phreatic groundwater flow system with shallow groundwater levels and groundwater supplies from the adjacent areas. Both study plots were selected so that the elevation of the plots above the nearby ditch was almost the same. The generally similar site conditions of the field plots made it possible to compare water balance components and groundwater consumption. The approximately 300 m distance from the nearby ditch minimized any effect that floods had on water table levels. Surface runoff was not observed since the slope of the plots was less than 2‰.

The naturally regenerated oak forest had 60% pedunculate oak (*Quercus robur*) which are 20-25 m high and the density is 270 trees ha⁻¹. The fallow plot, situated about 3 km from the oak plot, is part of an agricultural field that had been plowed in the past, but it has not been seeded and cultivated now for several years and is under natural succession. The vegetation consists of furrow-weed with species like *Solidago gigantea*, *Artemisia vulgaris*, *Amaranthus retroflexus* and *Ambrosia artemisiifolia*.

The vertical distribution of the root system was surveyed in situ by taking three replicate volumetric soil core samples at six depths (0-0.2 m, 0.2-0.4 m, 0.4-0.6 m, 0.6-0.8 m, 0.8-1.0 m and 1.0-1.2 m) for both study plots. After separating the fine roots (diameter < 2 mm) by sieving the soil samples, they were scanned and the total

root extent of each sample was determined by grid-counting. Finally, the fine root fraction of each layer was related to the total root extent of the profile. Fine roots reduced approximately linearly with depth at the oak plot (estimated root depth: 1.5 m) and logarithmically at the fallow plot (estimated root depth: 0.8 m).

The soil analyses included the sieving and hydrometer analyses of particle size distribution of the soil samples, taken at 0.2 m intervals down to a depth of three meters. At both plots the soil texture was compacted fine sand (0.02–0.2 mm) close to the surface varying between 80–99%. The clay and silt fractions were high below one meter depth at both plots and reach 30–35% and 20–25%, respectively. Three repetitions of undisturbed soil samples for water retention were analysed at depths of 0.1, 0.3, 0.5, 0.7, 0.9 and 1.2 m by cylinders of 100 cm³.

The maximum of the Leaf Area Index LAI (m² m⁻²) was estimated by collecting leaf litter on the ground. At the oak plot, newly defoliated leaves were collected carefully from five locations (1 m² × 1 m) during late autumn of 2007 and dried in an oven (105°C for 24 hours). Determination of LAI included the calculation of the ratio of weight to leaf area for a subset of leaves and then for the whole sample. The average LAI of the samples was 3.9 m² m⁻². The 16-day Enhanced Vegetation Index (EVI) product of MODIS (Moderate Resolution Imaging Spectroradiometer) was used to describe the seasonal change of LAI. The 250 m resolution EVI was converted to LAI using the relationship, proposed by Wang et al. (2005).

At the fallow plot, the maximum leaf area index was estimated by leaf collection from three locations (0.5 m² × 0.5 m). All the collected leaves were scanned and the leaf area was determined by grid counting. The mean LAI of the three samples was 1.1 m² m⁻². The same leaf area index was used throughout the vegetation period. During the dormant season, we assumed the LAI 0.5 m² m⁻², based on the biophysical parameter table of Steyaert & Knox (2008) (Fig. 12).

The albedo was derived from the 16-day estimates of the MODIS images. The missing values of albedo in winter were assumed as snow cover and were replaced by an albedo of 45% at the oak and 75% at the fallow plot (Kondratiev 1969).

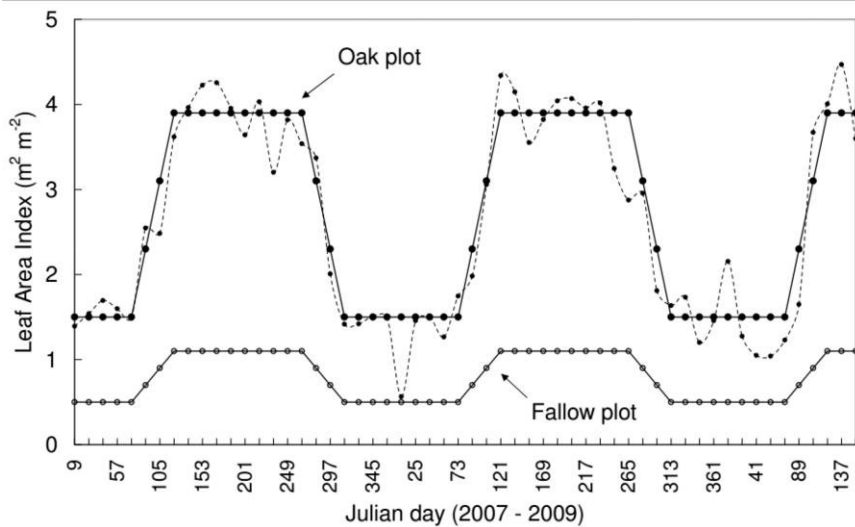


Figure 12. Seasonal change of LAI (Oak plot: dashed line - MODIS data, solid line - applied in the model, Fallow plot: solid line - applied in the model).

Monitoring at the plots

Meteorological variables, soil water content and groundwater level were monitored by automatic equipment.

A weather station (iMETOS, Pessl Instruments, Austria) at the fallow plot and an automatic rain-gauge (Rainlog Data Logger, Rainwise, USA) 500m from the oak plot was employed to monitor weather conditions. The volumetric water content was monitored with FDR (Frequency Domain Reflectometers) using Decagon EC-5 probes (Decagon Devices, Pullman, USA) with a time interval of 15 min. The probes were installed at depths of 0.1, 0.3, 0.5 and 0.7 m. Groundwater level was measured by a Dataqua DA-S-LRB 118 vented pressure transducer (Dataqua Elektronikai Kft., Balatonalmádi, Hungary) with time interval of 15 min. Manual groundwater level measurements were used to verify the reliability of the monitoring.

Water balance modelling with Hydrus 1-D

Model structure. The Hydrus 1-D (Simunek et al. 2005) model was applied for estimation of soil water content changes, actual transpiration and soil surface evaporation at both plots. Hydrus 1-D is a modelling software for analyses of water flow and solute transport in variably saturated porous media. The base of the model is the variable saturated vertical flow domain, where water flow is simulated (Fig. 13).

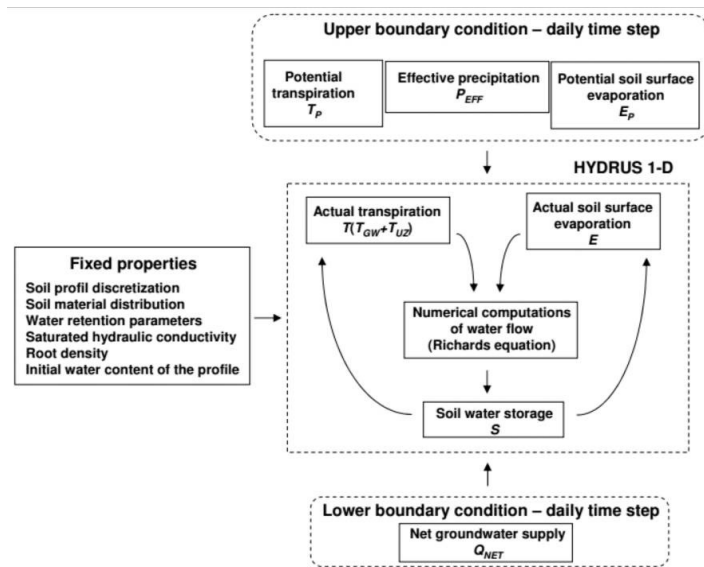


Figure 13. Structure of the model (P_{EFF} : effective precipitation, T_p : potential transpiration, T : actual transpiration, T_{GW} : groundwater consumption, T_{UZ} : transpiration from the unsaturated zone, E_p : potential soil surface evaporation, E : actual soil surface evaporation, Q_{NET} : net groundwater supply, S : soil water storage). All components are in mm day^{-1} .

The calculation of effective precipitation, canopy and litter interception loss, potential transpiration and soil surface evaporation, net groundwater supply, actual transpiration and soil surface evaporation is introduced by Móricz (2010) more in detail.

Model calibration. The observed soil water content and groundwater level data were employed to calibrate the Hydrus model at both plots. The model was calibrated specifically for this two year period and not used for future simulation (Móricz 2010).

2.2.3 Results

Comparison of observed and modelled results

The calibrated soil water contents compared well with observations at both plots (Fig. 14).

The discrepancies at the beginning of the growing season of 2007 in measured versus modelled soil water content may be attributed to the disturbance of the soil profile and vegetation at both plots during installation of the monitoring equipment. There were deviations at the fallow plot at a depth of 10 cm in December, 2008 and January, 2009 due to strong soil water freezing.

The calibrated groundwater levels compared quite well with measurements at both plots. Due to a malfunction of the pressure transducer, the continuous measurement failed at the fallow plot between November, 2007 and June, 2008. During this period regular manual groundwater depth measurements were employed to follow groundwater levels at the fallow plot.

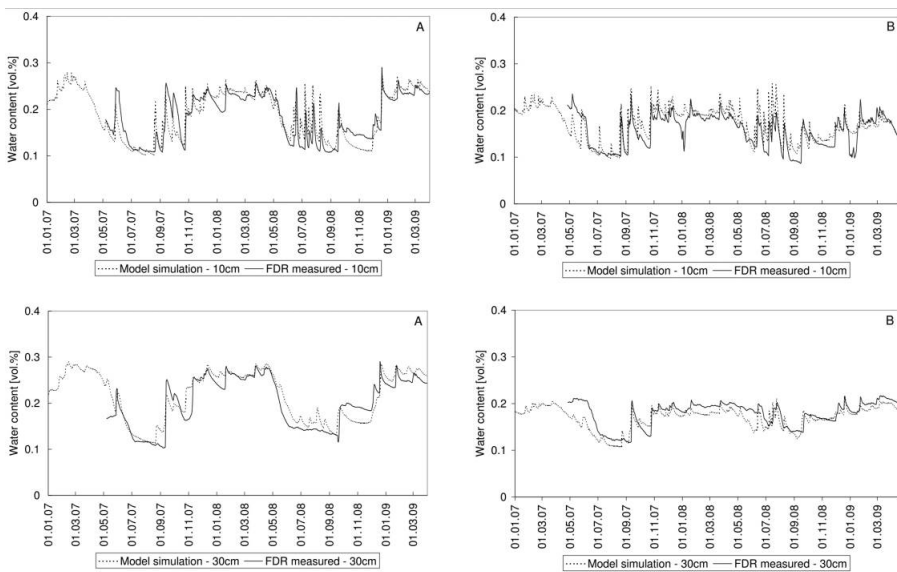


Fig. 14 - Comparison of measured and calibrated soil water contents at the oak (A) and fallow (B) plots

Water balance results

Total rainfall interception was twice as much in the forest than at the fallow plot considering the whole study period. In the 2007 growing season, 38% of the rainfall was intercepted at the oak plot, while at the fallow plot it was only 15% of the gross rainfall. As a consequence of more rainfall in 2008, the ratio of interception loss to precipitation decreased slightly at both plots.

According to the Hydrus model, the oak forest transpired approximately 33% more than the fallow vegetation while groundwater consumption was three times higher during the study period.

Actual soil surface evaporation was only 4% of the total evapotranspiration at the oak plot and 26% at the fallow plot during the whole study period. The low evaporation amount of the oak plot was the consequence of the high surface resistance due to the litter layer and the shading effect of the canopy. Available net radiation at the soil surface, and soil surface evaporation rates were higher at the fallow plot; thus the soil surface dried out more rapidly than at the oak plot.

Since weather conditions were quite contrasting during the growing seasons of 2007 and 2008 we decided to compare the water balances for both plots from 1st of April until 30th of September.

Groundwater consumption T_{GW} was computed using the temporal changes of the capillary fringe in the Hydrus model results, which was 66% of the total transpiration at the oak plot while at the fallow plot it was only 38% in the growing season of 2007 (Fig. 15).

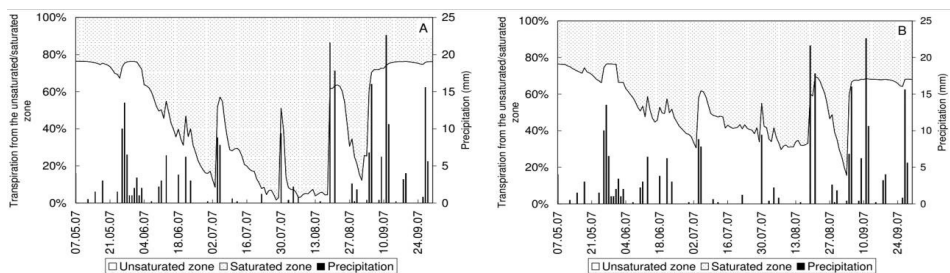


Figure 15. Proportion of the water uptake from the unsaturated and saturated zone and precipitation at the oak (A) and at the fallow (B) plots during the growing season of 2007

In this growing season, the water uptake showed the effect of drought in summer. Until the start of the summer, the transpiration from the unsaturated zone T_{UZ} was considerable from the total transpiration. The fraction of groundwater consumption increased to 60% at the fallow and to 90% at the oak plot in summer.

In the growing season of 2008, rainy weather provided a considerable amount of moisture for the unsaturated zone; thus the groundwater consumption was reduced from the preceding year. Groundwater consumption at the oak plot was 50% of the total transpiration while at the fallow plot it was 25% in the growing season of 2008 (Fig. 16).

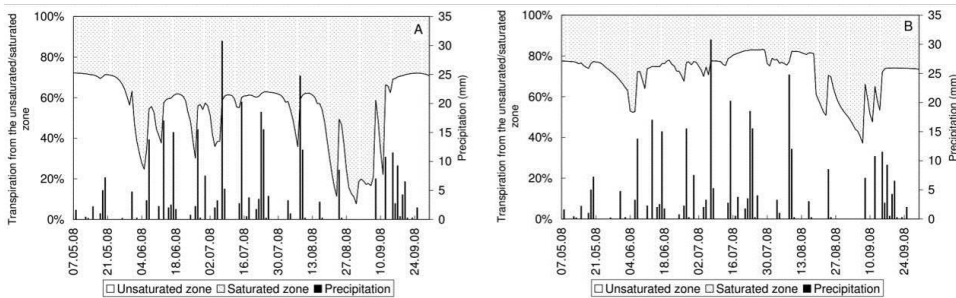


Figure 16. Proportion of the water uptake from the unsaturated and saturated zones and precipitation at the oak (A) and at the fallow (B) plots during the growing season of 2008

While in the growing season of 2007, both vegetation covers relied significantly on groundwater resources, in 2008 the evapotranspiration loss of groundwater was reduced considerably due to the rainy weather at both plots.

The water balance components of the growing seasons of 2007 and 2008 are shown in Tab. 1.

Table 1. Water balance components (mm) of the growing seasons of 2007 and 2008 at the oak and fallow plots

Water balance components	Growing season - 2007		Growing season - 2008	
	Oak plot	Fallow plot	Oak plot	Fallow plot
Precipitation (<i>P</i>)	261	261	383	401
Interception loss (<i>I</i>)	95	39	129	50

Soil surface evaporation (E)	22	139	41	154
Transpiration from unsaturated zone (T_{UZ})	208	235	255	260
Groundwater consumption (T_{GW})	405	144	255	87
Net groundwater supply (Q_{NET})	289	125	184	55
Change of soil water storage (S)	-180	-171	-112	-95

A meteorological tower was not set up at the oak plot, which contributed to the deviations of modelling results from the measurements. Air temperature and relative humidity at the fallow plot were applied above the canopy of the oak forest, which had an influence on the computation of potential transpiration and evaporation.

The empirical approach for computing Q_{NET} is further source of uncertainty since it is sensitive to the quality, the time-step of the record of groundwater levels and the readily available specific yield. The groundwater level data was carefully examined and suspicious measurements were not considered for further computation. The time-step for calculation of Q_{NET} was half an hour, considering the 15 min frequency of groundwater level readings, suggested by Gribovszki et al. (2008). The final value of the readily available specific yield was set to constant despite of its inherent variable nature in space and time.

2.3 Conclusions

Water balance components of an oak and fallow plot were estimated from 1 April, 2007 to 1 April, 2009 by calibrating the Hydrus 1-D model using soil moisture and groundwater level measurements. The study period included a dry (2007) and a wet growing season (2008).

For the entire study period, the Hydrus 1-D model results have shown that the total transpiration of the fallow plot was only two thirds that of the oak plot, while the soil surface evaporation in the oak plot was approximately one fifth of that in the fallow plot. The separation of transpiration into unsaturated transpiration and groundwater consumption has revealed that the groundwater consumption at the oak plot was almost three times higher than at the fallow plot. The groundwater consumption was

close to 60% of the total transpiration at the oak forest and approximately 30% at the fallow plot.

By comparing the dry (2007) and wet (2008) growing seasons, we found that groundwater consumption was approximately 40% less in the wet than in the drier growing season, despite the fact that the groundwater level was deeper during the dry period. Thus, during the dry season both vegetation covers relied considerably on the available groundwater resources.

The results of the study have reinforced those previous studies that reported higher groundwater consumption of forests compared to other vegetation covers. Therefore, future afforestation in arid regions with shallow groundwater levels should pay attention to the large groundwater depleting effect of forest, especially in light of future climate change and human water extraction.

RELATED WEBSITES, PROJECTS AND VIDEOS

Forests and water (FAO): <http://www.fao.org/docrep/010/a1598e/a1598e02.htm>

Books: http://www.nap.edu/catalog.php?record_id=12223

<http://www.springer.com/earth+sciences+and+geography/earth+system+sciences/book/978-94-007-1362-8>

Forest hydrology research: <http://www.forestry.gov.uk/fr/HCOU-4U4JAM>

water cycle animation: http://www.youtube.com/watch?v=o_cozZfC8c

land cover and hydrology of watersheds: <http://www.youtube.com/watch?v=t632Bz8AQoU>

<http://www.youtube.com/watch?v=t632Bz8AQoU>

http://www.youtube.com/watch?v=1Nr31_gjJYo&list=PL1JyimMkAKOibeSAzSLZVs56OjFU4pvi7

<http://www.youtube.com/watch?v=2cFOYvtJew&list=PLp5bLxICz17xssk-ftKyQ7zI62MoExlOf>

<http://www.youtube.com/watch?v=DouAIOT66Wo&list=PLp5bLxICz17xssk-ftKyQ7zI62MoExlOf>

<http://www.youtube.com/watch?v=hUo6Vir2lpc>

<http://www.youtube.com/watch?v=4yT3nJiJ8Gc&list=PLC30C7F922760EE2F>

REFERENCES

Andressian V (2004). Waters and forests: from historical controversy to scientific debate. **Journal of Hydrology** 291: 1-27.

Betts RA, PM Cox, SE Lee, FI Woodward (1997). Contrasting physiological and structural vegetation feedbacks in climate change simulations. *Nature* 387: 796-799

Bonan GB (2004). Biogeophysical feedbacks between land cover and climate. In: R.S. DeFries, G.P. Asner, and R.A. Houghton (eds) *Ecosystems and Land Use Change*. Geophysical Monograph 153: 61-72, American Geophysical Union, Washington, D.C.

- Bonan GB (2008). Ecological climatology. Cambridge Univ. Press, Cambridge, ed. 2., 568p
- Borsy Z, Csongor É, Sárkány S, Szabó I (1981). Phases of blown-sand movements in the North-East part of the Great Hungarian Plain. *Acta Geogr. Debr.* 20: 5-33.
- Bosch JM, Hewlett JD (1982). A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology* 55: 3-23.
- Brovkin V (2002). Climate-vegetation interaction. *J. Phys. IV France* 12: 57-82 doi: 10.1051/jp4:20020452
- Brutsaert W (1982). Evaporation into the atmosphere: theory, history, and applications. D.Reidel, Hingham MA, 299 p.
- Cardon GE, Letey J (1992). Plant water uptake terms evaluated for soil water and solute movement models. *Soil Science Society of America Journal*, 56 (6): 1876-1880.
- Chang M (2006). Forest Hydrology. An Introduction to Water and Forests. Taylor & Francis Group, USA
- Dingman S (2002). Physical Hydrology. Prentice Hall, Upper Saddle River. 646p
- Federer CA, Vörösmarty C, Fekete B (2003). Sensitivity of annual evaporation to soil and root properties in two models of contrasting complexity. *Journal of Hydrometeorology* 4: 1276-1290.
- Gash JHC (1979). An analytical model of rainfall interception by forests. *Quarterly Journal of the Royal Meteorological Society* 105: 43-45.
- Gálos B, Lorenz Ph, Jacob D (2007). Will dry events occur more often in Hungary in the future? *Environmental Research Letters* 2, 034006 (9pp) doi: 10.1088/1748-9326/2/3/034006
- Green TR, Taniguchi M, Kooi H, Gurdak JJ, Allen DM, Hiscock KM, Treidel H, Aureli A (2011). Beneath the surface of global change: Impacts of climate change on groundwater. *Journal of Hydrology* 405: 532-560.
- Gribovszki Z, Szilagyí J, Kalicz P (2010). Diurnal fluctuations in shallow groundwater levels and streamflow rates and their interpretation - A review, *Journal of Hydrology* 385 (1-4): 371-383.
- Hewlett J D (1982). Principles of forest hydrology, The University of Georgia Press, Athens, GA 183p
- Hydrus 1D for Windows, PC-PROGRESS (2008). [Online: 06 September 2011] URL: <http://www.pc-progress.com/en/Default.aspx?HYDRUS-1D>.
- Hungate BA, GW Koch (2002). Global Environmental Change: Biospheric Impacts and Feedbacks. In J Holton, J Pyle, J Currie (eds.) *Encyclopedia of Atmospheric Science* Academic Press, Ltd. 876-885
- IPCC 2007. Climate change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change <http://www.ipcc.ch>
- Járó Z (1959). A levélfelület nagysága néhány erdőtípusban. *Erdészeti Kutatások* 6: 103-108
- Justice CO, Townshend JRG, Vermote EF, Masuoka E, Wolfe RE, El-Saleous N et al. (2002). An overview of MODIS land data processing and product status. *Remote Sensing of Environment* 83: 3-15.
- Kleidon A and M HEIMANN (1998). Optimised rooting depth and its impacts on the simulated climate of an Atmospheric General Circulation Model. *Geophysical Research Letters* 25: 345-348
- Kleidon A, K Fraedrich, C Low (2007). Multiple steady-states in the terrestrial atmosphere-biosphere system: a result of a discrete vegetation classification? *Biogeosciences*, 4: 707-714 doi: 10.5194/bg-4-707-2007
- Kondratiev KY (1969). Radiation in the Atmosphere. Academic Press, New York, USA.

- Maitre DCL, Scott DF, Colvin C (1999). A review of information on interactions between vegetation and groundwater. **Water South Africa** 25: 137-152.
- Móricz N (2010). Water Balance Study of a Groundwater-dependent Oak Forest. **Acta Silvatica&Lignaria Hungarica** 6: 49-66.
- Nachabe M, Shah N, Ross M, Vomacka J (2005). Evapotranspiration of two vegetation covers in a shallow water table environment. **Soil Science Society of America Journal** 69: 492-499.
- Pitman (2003). The evolution off, and revolution in, land surface schemes designed for climate models. *Int. J. of Climatol.* 23: 479-510 doi: 10.1002/joc.893
- Roberts J, Rosier P (2005). The impact of broadleaved woodland on water resources in lowland UK: I. Soil water changes below beech woodland and grass on chalk sites in Hampshire. *Hydrology and Earth System Sciences* 9 (6): 596-606.
- Schilling KE (2007). Water table fluctuations under three riparian land covers, Iowa (USA). *Hydrological Processes* 21: 2415-2424.
- Šimůnek J, van Genuchten MT, Šejna M (2005). The Hydrus-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media. Version 3.0, HYDRUS Software Series 1, Department of Environmental Sciences, University of California Riverside, Riverside, CA, pp. 270.
- Steyaert LT, Knox RG (2008). Reconstructed historical land cover and biophysical parameters for studies of land-atmosphere interactions within the eastern United States. *Journal of Geophysical Research* 113, D02101, 27 PP, doi: 10.1029/2006JD008277.
- Valente F, DAVID JS, GASH JHC (1997). Modelling interception loss for two sparse eucalypt and pine forests in central Portugal using reformulated Rutter and Gash analytical models. *Journal of Hydrology*, 190: 141-162.
- Van Genuchten, MT (1987). A numerical model for water and solute movement in and below the root zone. Research Report No 121, U.S. Salinity laboratory, USDA, ARS, Riverside, California, 221 1987.
- Von Hoyningen-Hüne J (1983). Die Interception des Niederschlags in landwirtschaftlichen Beständen. *Schriftenreihe des DVWK* 57: 1-53.
- Wang Q, Adiku S, Tenhunen J, Granier A (2005). On the relationship of NDVI with leaf area index in a deciduous forest site. *Remote Sensing of Environment* 94: 244-255.

3 CARBON CYCLE: THE ROLE OF FOREST VEGETATION

3.1 Introduction

Climate regulation through carbon sequestration is one of the ecosystem services of forests. They are the largest terrestrial C pool thus can have an important role in climate change mitigation. Exchanges of carbon between forests and the atmosphere are being influenced by human-caused and natural disturbances. In this way, land use changes - especially afforestation and deforestation - can have major impacts on carbon storage. Forest soils are also an important pool of carbon. They too are a vital

part of the carbon cycle and can act as both sources and sinks. Forest ecosystems-climate feedbacks under future climate conditions are still large unknowns.

Organic matter production of forests strongly depends on soil, hydrological, and climatic circumstances, at the xeric forest limit primarily on the recurrent summer droughts. In the comparison of climate zones, the strong correlation between organic matter production and climate is obvious. The above-ground dendromass responds strongly to the worsening of climate, irrespective of tree species, while the below-ground parts remain unchanged. The carbon content of humus and soil increases toward drier climate.

3.2 Ecosystem services of forests

There are a number of components to the broad range of ecological services that forests provide. These include (Sousson et al.,1995):

- the regulation of water regimes by intercepting rainfall and regulating its flow through the hydrological system;
- pollution control;
- the maintenance of soil quality and the provision of organic materials through leaf and branch fall;
- the limiting of erosion and protection of soil from the direct impact of rainfall;
- regulating climate (e.g. C-sequestration); and
- being key components of biodiversity both in themselves and as a habitat for other species.

This chapter will focus on the carbon cycle and sequestration of the forest ecosystems.

3.3 Carbon cycle of forests

Forests play a key role in the carbon cycle. Through the process of photosynthesis they are able to absorb carbon dioxide from the atmosphere (figure 16). Trees partition the carbon that they capture into different products such as leaf, root, seed, wood and branch, these different fractions are referred to as biomass. Much of the carbon

that is initially captured is emitted back into the atmosphere during respiration and decomposition. Only the carbon that is stored in woody biomass such as roots, stems and branch material is locked away for the longer term.

Exchanges of carbon between forests and the atmosphere are being influenced by human-caused and natural disturbances (e.g. forest fire, forest cutting). In case of deforestation, the stored carbon will be released to the atmosphere quickly or to the soil where it decomposes slowly and increases soil carbon content. In this way, land use changes - especially afforestation and deforestation - can have major impacts on carbon storage.

Forest soils are also an important pool of carbon. They too are a vital part of the carbon cycle and can act as both sources and sinks. At global scale the carbon that is contained in the world's forests, if released would be enough to raise the carbon dioxide concentration in the atmosphere to over 1000 ppm and with it would follow a potentially catastrophic rise in temperature of 5-8°C. At a global scale maintaining the world's woodlands and forests is therefore an essential element of any measure to mitigate climate change.

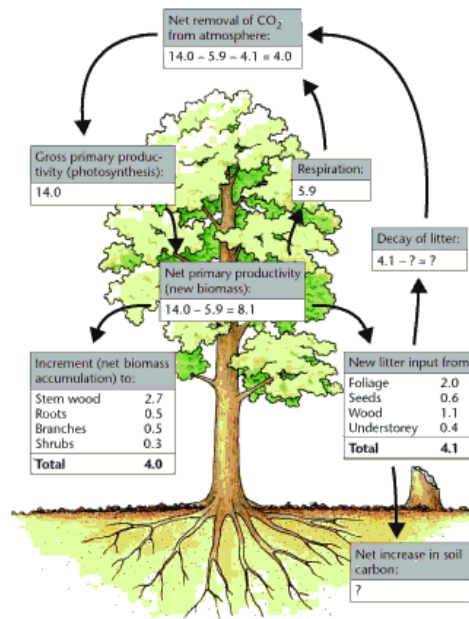


Figure 16. Carbon cycle of trees

Table 2 shows that average carbon levels sequestered in vegetation and soils differs among the major biomes. and among regions (figure 17).

Table 2. Average Carbon Stocks for Various Biomes (in tons per acre)

Biome	Plants	Soil	Total
Tropical forests	54	55	109
Temperate forests	25	43	68
Boreal forests	29	153	182
Tundra	3	57	60
Croplands	1	36	37
Tropical savannas	13	52	65
Temp. grasslands	3	105	108
Desert/s ernidesert	1	19	20
Wetlands	19	287	306
Weighted Average	14	59	73

Source: Adapted from Intergovernmental Panel on Climate Change, "Table 1: Global carbon stocks in vegetation and carbon pools down to a depth of 1 m [meter]," Summary for Policymakers: Land Use, Land-Use Change, and Forestry. A Special Report of the Intergovernmental Panel on Climate Change, at <http://www.ipcc.ch/pub/srlulucf-e.pdf>, p. 4.

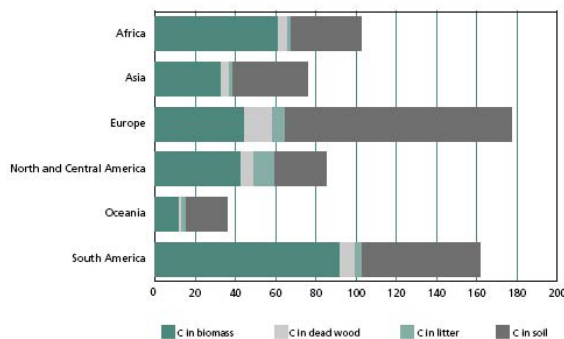


Figure 17. Total Carbon Stock (C) in forests by region 2005. Source: FAO: Global Forest Resources Assessment 2005, Progress towards sustainable forest management, Chapter 2: Extent of forest resources, p.35

The natural carbon sinks that can absorb and store carbon are ocean, forests, soil, peat and wetlands. In this way they can have an important role in climate change mitigation. Forest ecosystems are the largest terrestrial C pool of them. They store more than 80 % of all terrestrial aboveground C and more than 70 % of all soil organic C. Bonan et al. (2008) and Jackson et al. (2008) point out the differences of carbon sequestration between boreal, tropical and temperate forests that should be analyzed together with their biogeophysical feedbacks on the climate to assess the possible climatic benefits of these ecosystems.

Net-growing forests cause sequestration of C. After harvesting the life-cycle of the wood products is decisive. Therefore forest management and societal decisions both have significant influence on the carbon balance (Jandl et al. 2006). The first and most significant option to enhance C sequestration potential of forests lies in the establishment of new forests (through afforestation or reforestation). A second option is to foster the slow formation of a stabilized soil C pool. The C sequestration potential in forest soils is large, although smaller than that of agricultural soils (Jandl et al. 2006).

Forest carbon stocks could be potentially conserved and enhanced through a wide range of activities such as:

- Planting and/or regenerating trees on barren or non-forested land, in degraded forests, and in agricultural and urban landscapes. This includes concepts such as afforestation, reforestation, forestation, forest rehabilitation, forest restoration, agroforestry, urban forestry and enrichment planting.
- Conserving existing forests and avoiding their degradation or conversion to alternative land use. This includes concepts such as avoided deforestation, Reducing Emissions from Deforestation and Forest Degradation (REDD), and conservation of forest carbon stocks.
- Improved or sustainable forest management using options such as reduced impact logging (RIL), longer rotations, mixed ages and species.
- Managing harvested wood products.
- Soil (including peatland) conservation and rehabilitation.
- Use of forestry products for bioenergy to replace fossil fuel use.

- Tree species improvement to increase biomass productivity and carbon sequestration.

Through the introduced carbon related processes, ecosystems alter the biogeochemical cycles, thereby change the chemical composition of the atmosphere (Pitman, 2003), thus can lead to the increase or to the reduction of the projected climate change signal. Increasing atmospheric CO₂ content can lead to reduced terrestrial carbon uptake and greater accumulation of carbon in the atmosphere (Bonan 2008), which is a positive feedback that in turn can result in further global warming. However, the carbon – climate feedbacks under future climate conditions are large unknowns. Global warming will mobilize a certain, still unknown, quantity of soil C due to stimulation of the mineralization rate (Jandl et al. 2006, Booth et al. 2012). Higher CO₂ concentrations can also lead to the increase of the stomatal resistance thereby to the inhibition of the transpiration, which can amplify the global warming (Cao et al. 2010, Gopalakrishnan et al. 2011). Therefore for the quantification of the net climatic benefits of forests an integrated assessment of the processes, as well as accurate field measurements and modelling studies would be essential.

3.4 Estimations of the carbon content of forests and forest soil at the xeric limit

3.4.1 Below- and aboveground carbon stock in the dendromass of native tree species in Hungary

Forestry, in practice, uses special climate categories represented by different tree species (i.e. beech, hornbeam-oak, sessile oak - Turkey oak, forest steppe: treeless). Beech climate can be characterized by most humid conditions, whereas forest steppe is the warmest and driest from the classes. These categories indicate different growing potential, therefore, any change in the area of climate categories accompanies with variation of organic matter production of the forest ecosystem (Führer et al., 2011a,b).

The ecological value of forest sites can be characterized by organic matter production, which is influenced by the climate in a greater rate, than it was thought before.

The organic matter production ability can be characterized in the easiest way by the accumulated timber volume in the growing stock in unit area. It was determined, that in unit area of climate categories used in practice, the organic matter accumulated

in the growing stock are the highest in Beech climate (321 m³/ha). In Sessile oak or Turkey oak climate it is only 207 m³/ha, and in forest-steppe climate it is less than 149 m³/ha.

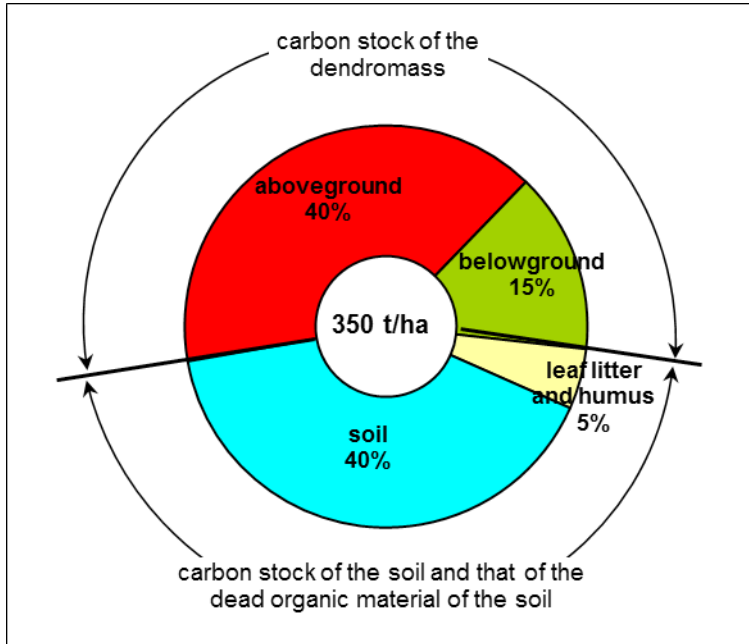


Figure 18. Carbon stock of the Turkey oak stand

Due to the climate change Turkey oak is becoming more and more important. The characteristic of Turkey oak is taproot system. When young it develops its roots deep into the soil very vigorously. Later lateral roots also become stronger and they will be able to develop farther from under the projection of the crown. In the experimental plot the volume of all roots in the upper 100 cm soil layer exceeds the 90% of the total root volume. This means that even if the soil conditions make possible the penetration of roots into deep layers, most of the root system encompasses and utilizes rather the one-meter tilth beneath the surface. Based on our measurements, the quantity of belowground dendromass (root swelling and root system) referring to carbon equivalent in the examined Turkey oak stand is 51 t/ha, of which 36 t/ha is in the root system. Its ratio out of the total dendromass (aboveground and belowground together) is 19 %. In a more unfavourable (drier) sample plot the value of 25% has

been measured at a similar age Turkey oak stand. Consequently, the favourable climate conditions affect the organic matter production positively, the aboveground dendromass is higher, both in terms of ratio and absolute value. In a warming climate the amount of aboveground dendromass and the organic matter production will decrease (Führer et al. 2011).

3.4.2 Carbon sequestration of forest ecosystems and climate change

The ecophysiological observations and the investigation of the physiological processes of forests depending on weather have clearly proved that water supply in the main growth cycle (May to July) and in the critical months (July and August) essentially influences the growth and organic matter production of the forest (Führer et al. 2011). Relationship between meteorological parameters and girth-growth of trees (proportional with organic matter production) can be characterized by a simplified forestry aridity index (FAI) for Hungarian conditions (Führer et al. 2011a). By this index, the average weather conditions of different climate categories applied in forestry practise can be described. The smaller is the value of the FAI, the cooler and rainier is the climate (beech climate can be characterized by the lowest, whereas Turkey oak climate by the highest FAI values) FAI shows a causal relationship with the average yearly organic matter production (Führer 2007). The calculated FAI values show strong correlation with the carbon sequestration of the forest stand. Figure 4 shows that under present climate conditions, carbon sequestration is declining with increasing aridity among the forest climate classes.

The results may be utilised for forecasting productivity changes according to various scenarios. Based on the results of regional climate model simulations for the country, summers are projected to be warmer and drier (Gálos et al. 2007). These can result in a drastic shift in the forest climate categories and a species composition change on long-term time basis (Führer et al. 2013). The beech climate is projected to almost disappear from Hungary, the first of all on the xeric limit of its distribution, and Turkey oak as well as forest steppe climate is expected to expand. Based on figure 4, it would lead to less carbon sequestration in the forest dendromass and a decrease in production capacity of stands.

We expect a significant area decrease in good forest yield classes together with an increase in poor categories. The decrease in yield is caused by decrease of lumbered wood volume and more valuable wood assortments, as well. In case of the projected

climate scenario, the highest decay in production capacity will be expected for Turkey oak (12 percent), while the lowest for beech (7.5 percent). (Führer et al. 2013).

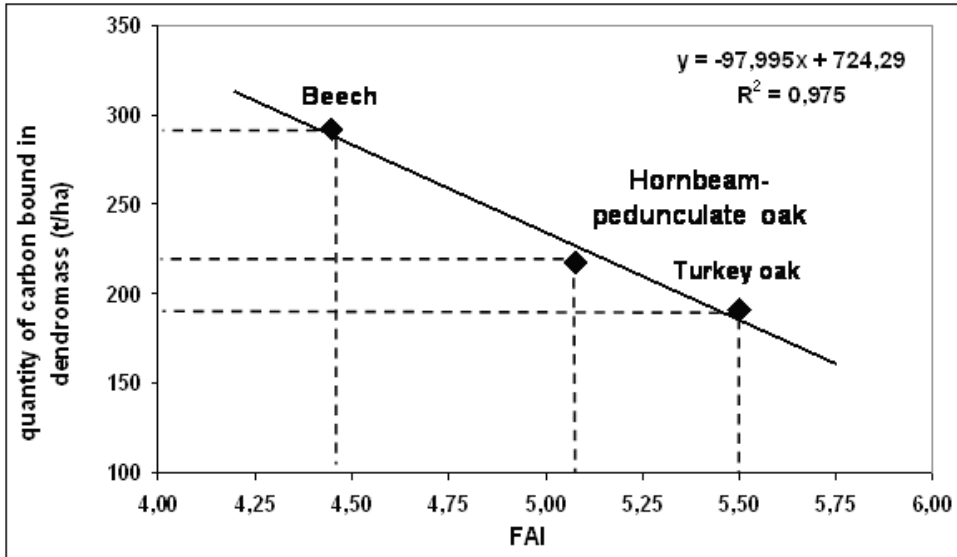


Figure 19. Correlation between aridity index (FAI) and the carbon stock stored in the dendromass of examined zonal forest types on optimal sites (Führer et al. 2011b)

The forecasted warmer and drier climate in growing season would also result in evident growth-loss of forest trees in Hungary. The growth-loss can be indicated by the decrease in wood volume of an area unit. Considering that cost of logging are determined mainly by the actual marketing circumstances independently on climate change; final consequence of the loss in production will be the decrease of revenues and profitability of forestry practice (Führer et al., 2013).

3.4.3 Soil carbon content and its estimated change under future climate conditions

Carbon content of forest soil and litter has been investigated in 35 deciduous forest plots in Southwest Hungary. Soil samples were collected from 0-5, 5-10, 10-20 és 20-30 cm depth, applying standardized methods. Weight, pH value, carbon and nitrogen content as well as the mechanic composition of the samples have been determined.

The volumetric weights of the certain soil layers were also estimated for calculating the carbon content.

Carbon content of the litter samples has been determined separately for leaves, needles, twigs and decomposed.

Litter contains 5 tons carbon/hectar and the upper soil layer 46 tons carbon/hectar, which is almost 10 times as much as in the litter (figure 20). The estimated variability within the layer is larger than the carbon content difference between the layers.

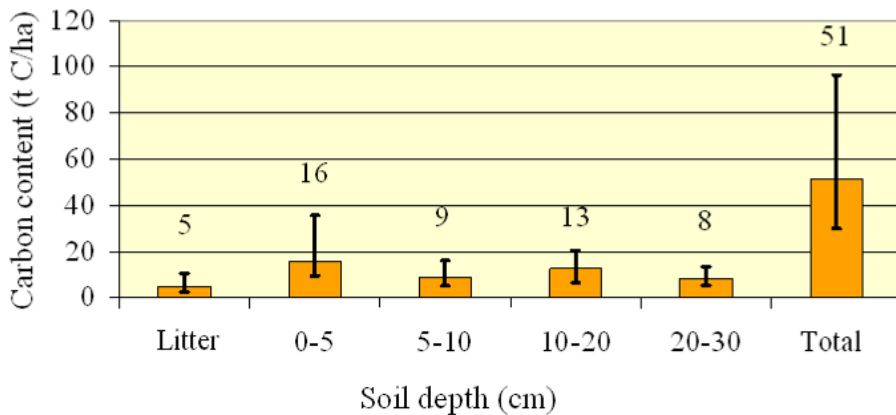


Figure 20. Carbon content of litter and forest soil

The drier and warmer climate can result in a decrease of the productivity of forests on the xeric (lower) limit of their distribution, where water availability is an important limiting factor. But it does not lead to the decrease of the carbon reserves of soil. The investigations and estimations showed that carbon reserves of soil may be higher under drier and extreme climate conditions. The reason for it is that the organic material and humus decomposition is prevented by drier climatic conditions in summer. 40-60 % of carbon stock of forest ecosystem can be found in underground organic matter in the Hungarian forests lands. The proportion of soil is 25-40% in total stock of carbon. It amounts to 27% carbon stored in dead organic material in the beech-wood forest, and 40% in Turkey oak forest. However, the total carbon of stock

of Turkey oak forest ecosystem was smaller, carbon of stock in soil was larger than in soil of beech-wood forest (Bidló et al. 2011).

Expected unfavourable ecological effect of climate change can be a high risk for forest management.

RELATED WEBSITES, PROJECTS AND VIDEOS

carbon cycle: <https://www.e-education.psu.edu/meteo469/node/160>

https://www.fas.org/irp/imint/docs/rst/Sect16/Sect16_4.html

<http://www.whrc.org/mapping/boreal/modeling.html>

UN-REDD Programme: Reducing Emissions from Deforestation and forest Degradation:

<http://www.un-redd.org/AboutREDD/tabid/102614/Default.aspx>

<http://www.thegef.org/gef/pubs/land-use-land-use-change-and-forestry-lulucf-activities>

Forests and climate change (FAO) – carbon and GHGs: <http://www.fao.org/docrep/005/ac836e/AC836E03.htm>

Soil properties and processes that control soil carbon accumulation: http://www.youtube.com/watch?v=seJhFW6h_1U

Projects:

<http://www.iww.uni-freiburg.de/researchareas/resource-and-carbon-storage>

<http://www.ucd.ie/carbifor/>

<http://www.forestry.gov.uk/fr/INFD-633DJ4>

<http://ucanr.edu/sites/forestry/Carbon/>

Forest carbon dynamics; National Forest Sinks Committee Forest Carbon Risk Analysis Project

<http://cfs.nrcan.gc.ca/projects/topic/36>

Forest carbon sequestration:

<http://www.youtube.com/watch?v=D-E-7RMbSZo>

<http://www.youtube.com/watch?v=5xQnFhIRR88>

REFERENCES

- Bidló, A., Juhász, P. Szűcs, P. Ódor P. (2011). Carbonstock of the soil in some West-Hungarian forestlands, *Geophysical Research Abstracts*, Vol. 13, EGU2011-7803, 2011, EGU General Assembly 2011
- Bonan, G.B. 2008. *Ecological climatology*. Cambridge University Press, UK, 550 p
- Bonan G.B. 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *Science*, 320, 1444–1449, doi: 10.1126/science.1155121
- Booth B B B, Jones C D, Collins M, Totterdell I J, Cox P M, Sitch S, Huntingford C, Betts R A, Harris G R, Jon Lloyd: High sensitivity of future global warming to land carbon cycle processes. *Environ. Res. Lett.* 2012, 7 024002 (8pp) doi:10.1088/1748-9326/7/2/024002
- Führer, E., Horváth, L., Jagodics, A., Machon, A., and Szabados, I., 2011a: Application of a new aridity index in Hungarian forestry practice. *Időjárás* 115: 103–118.
- Cao L, Bala G, Caldeira K, Nemani R, Ban-Weissa G: Importance of carbon dioxide physiological forcing to future climate change. *Proc. Natl. Acad. Sci.* 2010, 107(21):9513-1918.
- FAO: *Global Forest Resources Assessment 2005, Progress towards sustainable forest management*,
- Führer, E., Marosi, Gy., Jagodics, A., and Juhász, I. 2011b: A klímaváltozás egy lehetséges hatása az erdőgazdálkodásban [Possible effects of climate change in the silviculture]. *Erdtud. Közl.* 1, 17–28. (in Hungarian)
- Führer E., Jagodics A., Juhász I., Marosi Gy., Horváth L. 2013. Ecological and economical impacts of climate change on Hungarian forestry practice. *Időjárás* 117: 159-174
- Gálos, B., Lorenz, P., and Jacob, D. (2007). Will dry events occur more often in Hungary in the future? *Environmental Research Letters*, doi: 10.1088/1748-9326/2/3/034006.
- Gopalakrishnan R, Bala G, Jayaraman M, Cao L, Nemani R, N H Ravindranath NH: Sensitivity of terrestrial water and energy budgets to CO₂-physiological forcing: an investigation using an offline land model. *Environ. Res. Lett.* 2011, 6 044013 (7pp). doi:10.1088/1748-9326/6/4/044013
- Jackson R.B., Randerson J.T., Canadell J.G., Anderson R.G., Avissar R., Baldocchi D.D., Bonan G.B., Caldeira K., Diffenbaugh N.S., Field C.B., Hungate B.A., Jobbágy E.G., Kueppers L.M., Nosetto M.D., & Pataki D.E. (2008). Protecting climate with forests *Environ. Res. Lett.*, 3, 044006 (5pp), doi: 10.1088/1748-9326/3/4/044006
- Jandl, R., Rasmussen, K., Tomé, M. and Johnson D.W. 2006. The Role of Forests in Carbon Cycles, Sequestration, and Storage. *IUFRO Newsletter*, Issue 4. Forest Management and Carbon Sequestration.
- Millennium Ecosystem Assessment 2005.
- Pitman A.J. (2003). The evolution off, and revolution in, land surface schemes designed for climate model. *Int. J. of Climatol.* 23, 479-510, doi: 10.1002/joc.893

4 BIODIVERSITY GENERATION AND CONSERVATION SERVICES - ECOSYSTEM, SPECIES AND GENETIC DIVERSITY

4.1 Introduction

The analysis of quantitative data of common garden tests supports the concept that these tests offer unique possibilities for the realistic simulation of effects of climate change scenarios. Within the distributional range of a species, the response of a population depends on its adaptedness to its local environment. At the xeric limit, selection pressure narrows genetic variation and the increase in frequency of extreme events may result in growth decline and mortality. In the humid part of range, climate selection is less effective.

The asymmetry of response in different environments supports the hypothesis that the simultaneous action of plasticity and selection *maintains an adaptive non-equilibrium also at genetic level, similar to the one at ecosystem level*. In the distributional range of low moisture stress, warming will ease plasticity strain, which leads to growth acceleration instead of “decoupling” from adapted climate. The opposite growth trends in Western and boreal Europe, versus South-eastern-continental and Mediterranean Europe can be explained by the described phenomenon.

As expected rapid changes in the next decades will affect first of all the extant (already existing) forest stands, adaptation potential will mainly depend on the level of phenotypic plasticity. The importance of this trait should be recognized not only in breeding and improvement, but also in selection and use of forest reproductive material.

4.1.1 Xeric limits and genetics

Trees, as dominant components of forest ecosystems, are of high ecological importance in the temperate belt and receive much attention with regard to adaptation potential and future risks of diversity loss and extinction. Much of the climate change literature however is based on simulations and models, the genetic background of which are often deduced from results with annuals or other fast reproducing organisms. Genetic analyses of forest trees demonstrate that their

genetic system and diversity parameters are *diametrically different* from annual plants or animals (Hamrick *et al.* 1992).

The crucial problem of realistic interpretation of adaptation to climate change is however the missing of field observations, such as common garden tests. In forestry, these tests have a very long tradition ("provenance tests"). Tests with trees are difficult to establish, laborious and time consuming to maintain and measure.

Another important field often missed when modelling and predicting responses to changes, is the production biology of forest trees (forest yield science). Large-scale assessments exist in forestry which analyse the response of forest stands to extant climate change effects and weather extremes (e.g. Briceno-Elizondo *et al.* 2006, Lapenis *et al.* 2005, Kramer and Mohren 2001). For instance, data show for large parts of Western Europe an unprecedented acceleration of forest growth in the recent warming decades, exceeding in some cases 50% (Spiecker *et al.* 1996). Interpreting these data might alleviate prediction difficulties of adaptive behaviour of tree populations. These shortcomings emphasise the importance of cross-disciplinary research (Mátyás 2006b).

4.1.2 Bioclimatic modelling of xeric limits needs genetic considerations

Climatic demands of tree species and of forest ecosystems have however attained a sudden actuality in the context of adaptation to predicted climatic changes. Bioclimatic modelling of distribution ranges is based on the concept that distributional patterns depend – among other factors – on the physiological tolerance limits to climatic effects. This generally recognised rule has to be extended by the statement that physiological tolerance is unquestionably determined by genetics. Tolerance can be defined as the ability of a genotype to maintain its fitness despite damage. It is also presumably genetically correlated with phenotypic plasticity, i.e. with growth vigour across environments (Weis *et al.* 2000; Mátyás and Nagy 2005). Limits of tolerance are therefore genetically set and will determine the presence or absence of species (Figure 21).

Thus, adaptive response to environmental stress is ultimately a genetic issue, and *correct bioclimatic modelling is strongly dependent on genetically set tolerance limitations.*

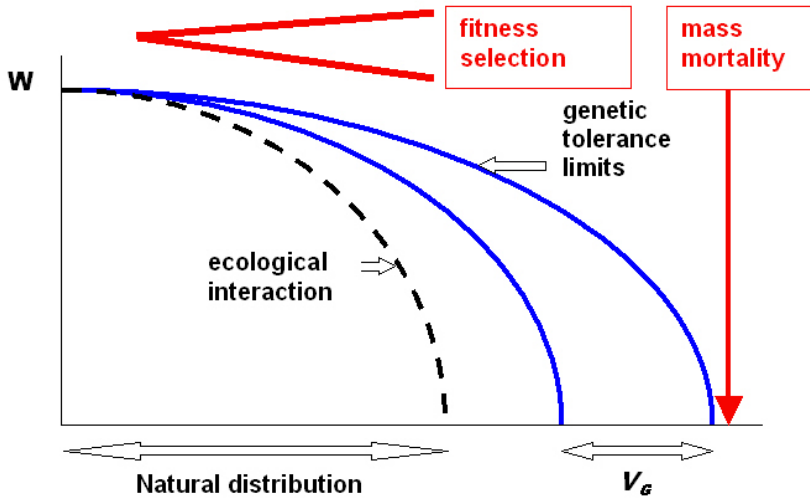


Figure 21. Ecological-genetic model of fitness decline and mortality triggered by worsening of climatic (site) conditions. The genotypic variance of limits of tolerance (V_G) represents the basis of natural selection. Due to competitive or trophic interactions in the ecosystem, the natural distribution is usually stronger limited, than the genetically set critical tolerance, as marked by the dashed curve (Mátyás 2006a)

4.1.3 Ecological and genetic options to adapt to changes at the xeric limits

Early symptoms of climate change effects at the xeric limits, such as loss of vitality, sporadic mortality, forest health problems indicate the constraints of adaptability. There are both genetic and non-genetic mechanisms operating on the individual, population, species and ecosystem levels, balancing changes in environmental conditions. On species and ecosystem or landscape level, a non-genetic possibility of responding to large-scale changes in the environment is *migration through seed dispersal*, including species substitution (succession, immigration) provided there are suitable species available.

Extensive studies on *long-distance gene flow through pollen* have shed light also on this very effective mechanism of constant replenishment of genetic resources, which most probably contributes to the unexpectedly high diversity and adaptability of tree populations (Hamrick *et al.* 1992). It is self-evident that migration and gene flow are functional across the whole range of distribution. Both mechanisms have however limited importance at the xeric limits, because they *rather support the escape of species and genes instead of the persistence* in marginal situations.

Genetically set adjustment mechanisms sustain persistence both on population and individual level. On the level of populations, *natural selection* adjusts the average fitness of a population to changing conditions. The directed genetic change of the population's gene pool towards an optimum state is genetic adaptation in the strict sense. It is a well accepted concept that the basic precondition for fast and effective genetic adaptation lies in sufficiently large variation, i.e. in sufficient genetic diversity (e.g. Booy *et al.* 2000, Beaulieu and Rainville 2004). Long-term genetic adaptability is therefore directly depending on the conservation or even reconstruction of broad adaptive genetic variance. The progress of selection will also depend on the intensity of selection pressure, as described by Fisher's theorem (Mátyás 2004). This progress may be counterbalanced by gene flow and migration.

Selection by climatic effects is certainly a key element among ecological factors. On the individual (genotype) level, *phenotypic plasticity* provides the ability to survive in a wide range of environments, without genetic change in the classic sense. Plasticity is the *environmentally sensitive production of alternative phenotypes by given genotypes* (DeWitt and Scheiner 2004). Plasticity implies that the phenotypic expression of genes is influenced by the environment, thus the organism may modify its responses within genetically set limits. It is especially effective in modular organisms such as trees, where the growth and developmental cycle may be strongly influenced by the environment. Phenotypic plasticity will set the limits of environmental heterogeneity within which a genotype or population can persist in its lifetime. In ecological literature, plasticity is often regarded as a non-genetic adaptation mechanism. It has to be emphasised that this trait is definitely heritable and also underlying climatic selection (Mátyás 2006a).

4.2 Estimation of aridity tolerance from common garden test results

4.2.1 Transfer analysis of common garden data

The principle of this approach is the use of ecological variables to express the change of environment through transfer to the test site. Adaptive responses to changes can be interpreted, generalized and compared more easily if expressed as ecological distances. To observe tolerance and plasticity, populations (provenances) are assessed in different environmental conditions. Regression analysis can be applied to describe the change in fitness. The slope of the function represents the sensitivity to changes and possible limits of tolerance. Taking growth and health condition as proxy for fitness, the function is interpreted as the species' reaction norm of fitness to the variable investigated (precipitation, drought). Thus, growth and survival of populations adapted to a given site, transferred and tested in other environments as part of common-garden tests, can be interpreted as a simulation of ambient changes at the original location. The transfer analysis validates the forecasting of adaptive response and of effects of environmental change (Mátyás and Nagy 2005; Rehfeldt *et al.* 2003).

4.2.2 Response to changes of climatic environment

Common garden tests of most tree species verify that populations originating from different climates show specific adaptation to local conditions and, accordingly, respond differently if grown under uniform conditions of a common garden.

The effect of temperature conditions on height growth of populations has been studied in six Scots pine tests situated in the centre of European Russia (Mátyás and Nagy 2005). The climate there is continental, summers may show moisture deficit. In order to exclude the effect of site quality, data were standardized by expressing height at age 16 in percents of locally adapted populations (relative height, see Figure 22). In the figure, transfer into cooler environments is shown by negative temperature sums. Tested populations were grouped according to their adaptedness into northern, central and southern groups.

The comparison of the regressions show that the three groups behave very similarly and display a marked depression in height growth with increasing aridity (i.e. higher mean temperature) of test location. This means that if introduced to more arid conditions than they were adapted to, populations react with growth decline expressed in relative height. On the other hand, the transfer into cooler (= more humid) environments resulted in growth acceleration compared to the local, autochthonous populations (Mátyás and Nagy 2005). Figure 2 illustrates that the simulation of climatic warming, i.e. the transfer into warmer environments, results in significant decline of productivity in the warmer part of the range, where moisture is in deficit in certain periods of the year.

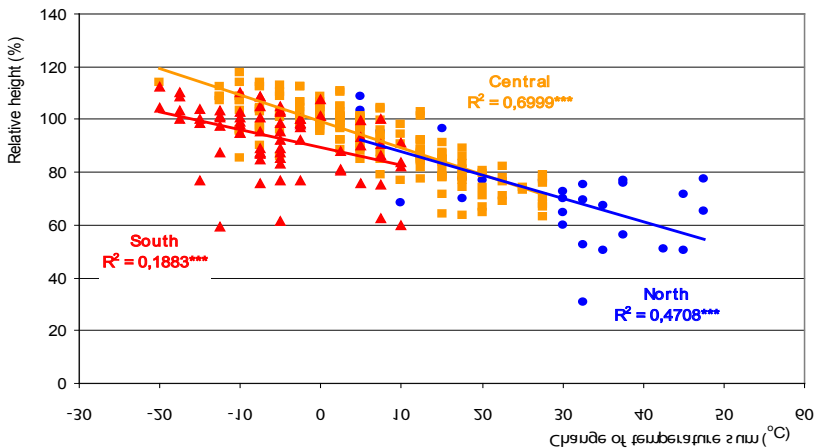


Figure 22. Linear regressions of relative tree height versus change of temperature sum (degree-days in °C) due to transfer by groups of provenances of Scots pine in 6 Russian tests (Mátyás and Nagy 2005)

4.3 Discussion

4.3.1 Adaptation maintains non-equilibrium state

It seems that the width of local adaptation is extended by phenotypic plasticity of genotypes towards less optimal environments. If environmental conditions improve (= transfer to milder sites), growth response will improve as well. Reaction norm of populations adapted to climates close to the xeric limit, exhibit an increased growth response northward of the original location. This effect is shown in figure 22.

It indicates that populations under climatic selection pressure adapt to local conditions simultaneously by genetic (natural) selection and by utilizing phenotypic plasticity. With increasing distance from climatic conditions of the physiological/genetical optimum for a given species, populations toward the climatic limits of distribution display an increasing genetic adaptation lag, buffered by phenotypic plasticity. As similar phenomena have been observed in numerous common garden experiments, on different species, cultivation or random effects such as gene flow are insufficient explanations. The migration hypothesis, i.e. that populations colonizing the site had no time yet to adapt locally, might hold at the thermal limits in the north, but not in the rest of the distribution area, and particularly not at the xeric limits. A parsimonious explanation is the assumption of adaptive non-equilibrium (Mátyás et al. 2008).

The proposed hypothesis of adaptive non-equilibrium means that within the distribution area of a (zonal) species, genetic adaptedness in the strict sense can be considered to be in an equilibrium state only in a narrow optimum zone. Approaching the thermal and xeric limits, the local populations get under increasing climatic stress due to the suboptimal functioning of genetic selection, which is buffered by phenotypic plasticity. Genetic diversity is then stabilised in a quasi-equilibrium state (Mátyás et al. 2008).

4.3.2 Conclusions for prediction and bioclimatic modelling of adaptive response

Asymmetry of response

An important outcome of transfer analyses is the asymmetry of response. The effect of environmental change on populations in different parts of the distribution range is divergent as different climatic factors exert their selection pressure.

The reaction of indigenous tree populations to warming will differ according to climatic zones. In the thermal-limited northern-boreal zone, the expected rise of temperature will lead to marked growth acceleration. At lower altitudes, in the temperate-maritime zone, growth will accelerate too, along with increasing or at least unchanged rainfall. In the sub-humid temperate-continental and sub-humid Mediterranean zones, however, even relatively minor temperature increases, coupled with growing drought stress, will trigger loss of compatibility, higher susceptibility to diseases, and increased mortality. At the xeric limits warming leads to relatively fast growth and productivity loss, and selective mortality (Berki and Rasztoivits 2004; Mátyás 2005). It should be noted that the described phenomena are generalisations. Substantial deviations may be caused by the genetic system of the species, the evolutionary-migratory past and regional or local climate effects. For example, there are indications that in certain regions of the boreal zone, where moisture stress is already present due to low precipitation, higher temperatures and increased drought stress may also lead to incremental decline (Lapenis *et al.* 2005).

Changes in genetic diversity following climatic stress

Expectable genetic changes will be minor in the northern part of the distribution range despite the extreme speed of predicted (and already ongoing) changes. Improved growing conditions can be utilized through the plasticity potential of tree populations, without much migration or selection. As inherited plasticity will determine the response to changes, there is little room left for genetic adaptation. In temperate-Atlantic Europe, where moisture stress is predicted to stay low, populations will also be well buffered by their adaptability.

The situation is completely different along the xeric limit of main tree species, and at the limit of closed temperate forests. Here, natural selection becomes effective in the form of irregularly appearing health decline and mortality waves following weather extremes. High selection rates will certainly exert a strong effect on the genetic resources of exposed populations, and if stress situations aggravate, it may lead to local population extinction, even for once well distributed, dominant species (Mátyás *et al.* 2008). This underlines the importance of management and conservation of forest genetic resources (Ledig and Kitzmiller 1992, Mátyás 2000).

4.3.3 Conclusions for mitigation and management

At the xeric limits of distribution, migration or gene flow from better adapted populations is not happening. Regarding interannual fluctuations, with increasing mean temperatures, severity of extremes will increase too: aridity stress will therefore increase, which will cause additional stress at the xeric limits. Fast genetic adaptation is in contradiction with the accepted assumption of strong biological and ecological constraints. At the (zonal) xeric limits, an unlimited adaptation to declining environment is unthinkable, due to the evolutionary tradeoffs and constraints. This is proven by remarkable migrations and area shifts in the geological past (Mátyás et al. 2008).

Therefore the need of human intervention in mitigation has to be underlined (Mátyás 2006a). Due to ecological constraints to spontaneous adaptation, the policy of artificial translocation should be preferred instead of extensive enhancement of connectivity, at least with regard to tree species.

4.3.4 Consequences for forest management

The urgent necessity to put into practice the findings of quantitative genetics cannot be questioned. In addition some aspects of forest management should not be overlooked when predicting responses and formulating mitigation strategies. Most of Europe's forests have been and still are under strong human influence, and are managed according to periodic management plans. Especially close to the xeric limit, the proportion of nature-close forests is low, regeneration is mostly artificial. E.g. in Hungary, the rate of artificial regeneration is at present over 70 % on the Great Plain. The possibilities left for spontaneous processes, such as migration and succession are limited. Forest stand composition is primarily determined by forest policy and economic considerations. This means also that adjustments in species composition and in adaptive genetic potential may be achieved faster and more effectively compared to natural, spontaneous processes (Mátyás et al. 2008).

In drought stress climates, increment loss and higher incidence of diseases and pests will challenge the economics of forest operations, and will shift the emphasis towards the maintenance of ecological functions and conservation of stability and of genetic resources (Geburek and Turok 2005).

REFERENCES

- Beaulieu, J., A. Rainville 2004. Adaptation to climate change: genetic variation is both a short- and long term solution. *The Forestry Chronicle*, 81: 5, 704–708
- Berki, I., E. Rasztovcics 2004. [Research in drought tolerance of zonal tree species, with special regard to sessile oak.] (in Hungarian with English summary) *In: Cs. Mátyás and P. Vig (eds.), Erdő és klíma – Forest and Climate IV*. Sopron, Hungary, 209–220
- Booy, G.R., J.J. Hendriks, M.J. Smulders [et al.] 2000. Genetic diversity and the survival of populations. *Plant Biol.*, 2(4): 379–395
- Briceno-Elizondo, E., G. Garcia-Gonzalo, H. Peltola, J. Matala, S. Kellomäki 2006. Sensitivity of growth of Scots pine, Norway spruce and silver birch to climate change and forest management in boreal conditions. *For. Ecol. Manage.*, 232: 152–167
- DeWitt, T.J., S.M. Scheiner 2004. Phenotypic variation from single genotypes. *In: DeWitt, T.J., S.M. Scheiner (eds.), Phenotypic Plasticity; Functional and Conceptual Approaches*. Oxford University Press, 1–9
- Geburek, T., J. Turok (eds) 2005. Conservation and Management of Forest Genetic Resources in Europe, Arbora Publ., Zvolen, Slovakia
- Hamrick, J.L., J.W. Godt, S.L. Sherman-Broyle 1992. Factors influencing levels of genetic diversity in woody plants. *New Forests* 6: 95–124
- Kramer, K., G. Mohren 2001. Long-term effects of climate change on carbon budgets of forests in Europe. *Alterra Report*, No. 194
- Lapenis, A., A. Shvidenko, D. Shepaschenko, S. Nilsson, A. Aiyyer 2005. Acclimation of Russian forests to recent changes. *Global Change Biology*, 11: 2090–2102
- Ledig, F.T., J.H. Kitzmiller, 1992. Genetic strategies for reforestation in the face of global climate change. *For. Ecol. Manage.*, 50: 153–169
- Mátyás, C. (ed.) 2000. Forest Genetics and Sustainability. Kluwer, Dordrecht
- Mátyás, C. 2004. Population, conservation and ecological genetics. *In: Burley, J., J. Evans, J. Youngquist (eds.), Encyclopedia of Forest Sciences*. Elsevier Major Reference Works, Oxford, Vol 1, 188–197
- Mátyás, C. 2006a. Migratory, genetic and phenetic response potential of forest tree populations facing climate change. *Acta Silvatica et Lignaria Hung.*, 2: 33–46 (<http://ASLH.NYME.hu>)
- Mátyás, C. 2006b. The missing link: synthesis of forest genetics and ecological research in view of challenges of environmental change. *In: G. von Wühlisch (ed.), Forest Genetics and its Contribution to Sustainability*. Mitt. BFH, Nr 221, Kommissionsverlag, Hamburg, 1–14
- Mátyás, C., L. Nagy 2005. Genetic potential of plastic response to climate change. *In: M. Konnerth (ed.), Tagungsberichte, Forum Genetik und Wald 2004*. Bav. Centre f. For. Repr. Material, Teisendorf, 55–69

- Mátyás, C., L. Nagy, É. Ujvári Jármay 2008. Genetic background of response of trees to aridification at the xeric forest limit and consequences for bioclimatic modelling. In: Strelcova, K., Cs. Mátyás, A. Kleidon, et al. (eds.) *Bioclimatology and natural hazards*. Springer Verl., Berlin 2008 179-196 pp.
- Rehfeldt, G.E., N.M. Tchebakova, L.I. Milyutin, E.I. Parfenova, W.R. Wykoff, N.A. Kouzmina 2003. Assessing population responses to climate in *Pinus sylvestris* and *Larix* spp. of Eurasia with climate transfer models. *Eurasian J. For. Res.*, 6 (2): 83–98.
- Spiecker, H., K. Mielikäinen, M. Köhl, J.P. Skovsgard (eds.) 1996. Growth trends in European forests. *EFI Report 5*, Springer Verl., Berlin
- Weis, A.E., E.L. Simms, M.E. Hochberg 2000. Will plant vigor and tolerance be genetically correlated? *Evol. Ecol.*, 14: 331–352

Climatic effects of land cover change

Áron Drüzler

ABSTRACT

Geological, paleontological and geomorphologic studies show that the Earth's climate has always been changing since it came into existence. The climate change itself is self-evident. Therefore the far more serious question is how much does mankind strengthen or weaken these changes beyond the natural fluctuation and changes of climate. Beyond the greenhouse effect and natural climate forcing processes (such as solar variability) there are also further anthropogenic influences with their various and partly non-negligible radiative effects. Land cover changes over time are one of the less successfully reconstructed anthropogenic influences on climate. It is well known that climate is the main factor of vegetation development through the precipitation, temperature, radiation and through the amount of carbon dioxide but the vegetation changes also affect the climate (partly as a feedback mechanism) via albedo, heat, water and momentum fluxes, as direct effects on the energy balance. There is also an indirect effect based on changes in the CO₂ concentration caused by the vegetation changes. This paper provides an overview of the scientific literature on climatic effects of land cover changes and through one detailed regional example (Hungary) also tries to show the mode of action of historical land cover changes on the regional climate system.

1 INTRODUCTION

Final aim of the climate research is to create correct forecasts for the future. For this reason we have to identify the individual processes which can influence our climate. Knowing the different climate forcing processes and evaluating the effects of their changes can help us to achieve this goal.

The atmospheric CO₂ concentration increase is well-known since the 18th century. This rise, together with the effect of other greenhouse gases, is equivalent to +2.5 Wm⁻² increments of the planetary radiation balance and to ca. 1.5 °C of equilibrium global warming. However, up to the present only +0.74 °C temperature increase was globally observed (IPCC, 2007). This means that effects of other climate forcing processes and internal mechanisms may have the same order of magnitude.

Beyond the greenhouse effect and natural climate forcing processes (such as solar variability, changes in solar orbital parameters, volcanic activity), there are also further anthropogenic influences, i.e. the effects of sulfate aerosols, land cover change, stratospheric ozone depletion, black- and organic carbon aerosols and jet contrails, etc., with their various and partly non-negligible radiative effects. A comparison of these effects during the past 250 years is presented in the IPCC Report (*Forster et al., 2007: Table 2.12 on p. 204.*)

Land cover changes over time are one of the less successfully reconstructed anthropogenic influences on climate. The surface albedo, emissivity, evapotranspiration, soil heat flux and the aero-dynamic roughness of an area are affected by land cover changes. The surface roughness length affects the efficiency of the vertical exchange between the surface and the atmosphere in the planetary boundary layer. The surface albedo and emissivity modify the short wave and long wave radiation budget. Vegetation controls the partitioning of vertical turbulent heat fluxes between their sensible and latent forms (Bonan, 2004) through the plant-specific rate of evapotranspiration to the potential one. (The latter presumes unlimited availability of water from the soil). In addition, the vegetation's shading also influences the soil heat flux. These processes have a provable impact on the near-surface temperatures and atmospheric humidity (Drüzler et al., 2010, 2011).

This paper provides an overview of the scientific literature on climatic effects of land cover changes (Section 2.) and through one detailed regional example (Hungary) also tries to show the mode of action of historical land cover changes on the regional climate system (Section 3.).

2 LITERATURE REVIEW

It is well known that climate is the main factor of vegetation development through the precipitation, temperature, radiation and through the amount of carbon dioxide (Budyko, 1974; Prentice, 2001; Nemani et al., 2003), but the vegetation changes also affect the climate (partly as a feedback mechanism) via albedo, heat, water and momentum fluxes, as direct effects on the energy balance. There is also an indirect effect based on changes in the CO₂ concentration caused by the vegetation changes (Pielke et al., 1998; Bonan 2002).

If all forests of the Earth were in their natural potential conditions, then their total areas would cover 52-59 million km² (Ramankutty and Foley, 1998; Klein Goldewijk, 2001). However, mankind uses a substantial part of its continental surface for agriculture and other purposes, e.g. deforestation, urbanization, overgrazing, etc. According to Crutzen (2002), ca. 50 % of the natural surfaces of continental areas have already been changed by mankind. Though this process started as early as the stabilization of climate ca. 10,000 BP, about 75 % of all forest reduction took place after the Industrial revolution.

The existence of the vegetation feedbacks on climate are already proven by empirical and model studies, on monthly and seasonal averaging and at local, continental and global scales, as well. In a part of these investigations the ocean-atmosphere feedback methodology (Frankignoul et al., 1998; Frankignoul and Kestenare, 2002) was adapted to the case of vegetation-atmosphere feedbacks, utilizing that dynamic memory of these feedbacks is also longer (1-2 months) than that of the atmosphere (1-2 weeks) (Liu et al., 2006; Notaro et al., 2006). In these studies the role of sea-surface temperature for the slow sub-system were played by the fotosynthetically active part of the solar radiation (FPAR), which value can be monitored from the satellites and characterizes the vitality of the vegetation.

According to these computations, the plant development depends mainly on temperature at the temperate latitudes, but it feeds back to the temperature, as well. This positive feedback may reach 10-25 % of the intra-monthly fluctuations. The feedback is the strongest in the cold-belt forests, e.g. in the Northern States of the USA and Canada, Northern Europe and Siberia. Here the feedback effect may be as strong as 1 °C

At the tropical and subtropical regions, however, the state of vegetation depends rather on precipitation. Though small feedback can be identified on precipitation in these regions, here the feedback does not reach 5 % of the total fluctuations. In some isolated areas, however, the amplifying feedback on precipitation may be higher than 10 mm/month. Such regions are e.g. North-East Brasilia, East-Africa, East-Asia and Northern part of Australia.

One of the most significant changes in land cover is the clearing of tropical forests in order to obtain new farmland, e.g. in the Amazon basin (Bonan, 2004). Though pastures of the tropical belt exhibit a higher albedo than the forests, it was still computed that some warming is the net result of the forest reduction (Gash et al., 1996, Gash and Nobre, 1997). The most likely cause of this warming is hidden in the root system of the trees, allowing much stronger transpiration in the dry and hot seasons (Kleidon and Heimann, 2000). The cooling effect of this mechanism, lost by deforestation is stronger than the warming effect of the albedo differences, as shown by model studies, (Bounoua et al., 2002).

The complete deforestation in Amazonia could already reduce the natural atmospheric precipitation, due to reduction of moisture sources for the atmospheric circulation (*Lean and Rowntree, 1997*). Partial clearing of tropical rainforests, however does not lead to precipitation reduction. Moreover, finer resolution models did even point at the possibility that existence of warmer spots within the forest cover may cause small-scale circulation, which could increase the convective activity (*Roy and Avissar, 2002*). Partial deforestation may even increase the precipitation of the Amazon region, itself, which is in coherence with the trends of precipitation observations (*Chagnon and Bras, 2005*).

Further model simulation targeted the effect of land cover changes on precipitation in the Eastern part of the USA (Pielke et al., 1997). In the experiment, there were differences only in the land cover parameters; all atmospheric initial and boundary conditions remained unchanged. In the weather case they chose, the natural vegetation led to intense convective cloudiness (cumulus congestus), but without precipitation. The same atmospheric conditions with the present agricultural land cover led to intense precipitation and thunderstorm activity. In the given period of time, the observations supported the latter case with heavy precipitation (Shaw et al., 1997).

In arid and semi-arid regions of our planet, agricultural land cover, overgrazing and the use of trees for fuel modifies the energy-balance of the surface, the hydrological cycle and, hence, the climate (Bonan, 2004). Overgrazing increases the surface albedo (Charney, 1975; Charney et al., 1977), which, in turn decreases the temperature and vertical instability. Hence the less convective cloudiness led to decreased precipitation in these belts. Therefore, degradation of the landscape can even enhance permanent drought. The more recent studies also supported that large scale changes in the land cover of the Sahel-belt could lead to decreased precipitation in the North African regions (Xue and Shukla, 1993; Clark et al., 2001).

Spatial contrasts between the dry and the irrigated agricultural lands may lead to strong contrasts in the sensible and latent heat balance of the two surface types (Bonan, 2004). This can induce mesoscale circulation (Avisar and Pielke, 1989; Chen and Avisar, 1994). High evapotranspiration from the irrigated surfaces can cool the near surface layers of the atmosphere, which causes local circulation which is similar to the sea-land circulation. The same contrast may lead the same circulation in the boundary between the hot natural areas and cooler irrigated areas. The irrigation causes cooler climate conditions in Northeastern Colorado in the USA (Chase et al., 1999).

The effect of vegetation on climate can be seen in the transition zone between the tundra and taiga (Bonan, 2004). Differences in the albedo of taiga and tundra ecosystems, which are strongly driven by the presence or absence of snow, can be an important regulating factor even at the larger scales of atmospheric circulation. The taiga warms climate in contrast with the neighbouring tundra vegetation, as shown in several studies (e.g. Thomas and Rowntree, 1992; Beringer et al., 2005).

Calculations based on the land cover dataset of Ramankutty és Foley (1998) show that the strongest global effects took place in the last 300 years as farms replaced forests. In the previous 700 years (between ca. 1000 and 1700 AD) there was no significant effect of the land cover changes on the global mean temperature. In the last 300 years, mean global temperatures increased 0.09 °C and temperatures in the Northern Hemisphere increased 0.15 °C due to land cover changes (Shi et al., 2007). In the temperate and high latitudes this increase was as high as 0.3 °C with no significant changes in the tropical and polar regions.

Further studies supported the small decreasing effect of land cover changes on temperature, (Bertrand et al., 2002; Matthews et al., 2003), but these studies did not consider the indirect effect through increasing the CO₂ content of the atmosphere. This could, however, change the land cover induced temperature changes from cooling to warming!

Between 1850 and 2000, an estimated 156 Gt of Carbon was emitted into the atmosphere due to deforestation (Houghton, 2003). Brovkin et al. (2004) found that land cover was responsible for 15-35 % of the anthropogenic CO₂ emissions, depending on the details of the reconstructions, according to Ramankutty and Foley (1998), Klein Goldewijk (2001), or Houghton (2003). The ca. 35 % proportion was also supported by Matthews et al. (2004) applying a similar methodology, i.e. climate-vegetation-carbon-cycle modelling. This means, that land cover changes are among the causes of the CO₂-induced global warming.

As fossil fuel burning increased rather fast in the recent century, the relative contribution of the land cover to the atmospheric CO₂ uptake decreased (Betts, 2006). Between 1850 and 1900 this value fluctuated between 42% and 68%, but in the 1990's this contribution was only 5-35 %. According to Matthews et al. (2004), the common direct and indirect effect of land cover changes could cause an increase of ca. +0.15 °C globally between 1700-2000. The global radiative effect of land cover change on climate was also estimated by Hansen et al (1998) and further reports were also published by the recent two IPCC Reports (2001, 2007).

Mika et al. (2006) used preliminary radiative modelling to show that the effects of historical land cover changes in Hungary in the second half of the 20th Century were comparable to the primary effect of the increase of CO₂ concentration on the radiation balance of the surface-atmosphere system in the same time period. This relation in the local radiation balance, however, does not allow an analogous comparison with the climate consequences due to the main differences between the two climate forcing processes. Namely, the greenhouse gases were changing in rather similar way all over the world. Hence these effects have been distributed evenly in space, whereas the effects of land cover are different in the different regions.

For further detailed investigations the MM5 high resolution, non-hydrostatic mesoscale model was used to analyze the climatic effect of historical land cover changes during the 20th century (Drüzler et al., 2011). This work tries to answer the following questions: (i.) What kind of impact could the land cover changes have

on the air temperature and dew point in Hungary? (ii.) How were these changes distributed in the country? (iii.) Could the land cover changes in Hungary affect the total precipitation in the last 100 years? (iv.) Could these differences of the land cover modify the individual precipitation events in the form of a possible "trigger effect"?

3 METHODS

3.1 Land Cover Data Arrays

The land cover changes were significant in Hungary during the 20th century according to the database of the Hungarian Central Statistical Office, and different historical maps. Two different land cover maps for Hungary were created in vector data format using GIS technology to restore the historical land cover changes. The land cover map for 1900 was reconstructed based on statistical data and two different historical maps: the derived map of the 3rd Military Mapping Survey of Austria-Hungary (*MMS*, 1910) and the Synoptic Forestry Map of the Kingdom of Hungary (*Bedő*, 1896). The land cover map for 2000 was derived from the CORINE land cover database (*CORINE*, 2000).

Significant land cover changes were found in Hungary during the 20th century according to the examinations of these maps and statistical databases.

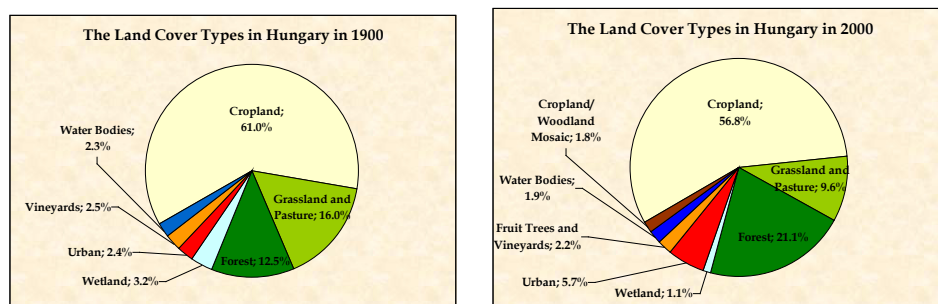


Figure 1. Fractional distribution of the land cover types in Hungary at the beginning (a) and at the end (b) of the 20th century

These maps show that the percentage of area of *cropland* in Hungary decreased from 61.0% to 56.8% between 1900 and 2000, while the urban areas increased from 2.43% to 5.69%. Significant changes also occurred in the percentage of *forests* and *grassland*. The forested area increased from 12.50% to 21.07%, while grassland decreased from 15.99% to 9.53% by 2000 (Fig.1).

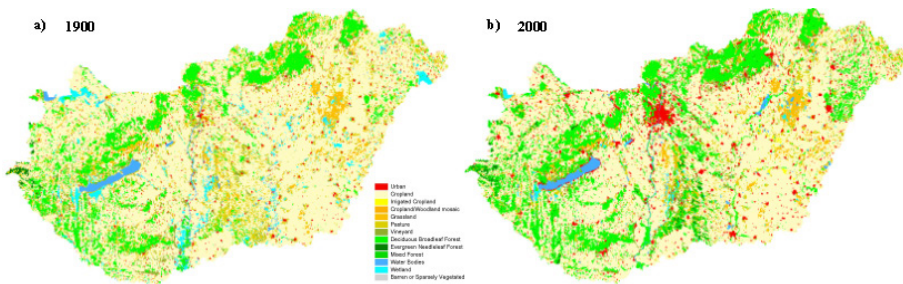


Figure 2. Land covers in Hungary at the beginning (a) and at the end (b) of the 20th century according to the MM5 land cover categories

3.2 MM5

The MM5 non-hydrostatic dynamic model (Grell et al., 1994) was used to further evaluate the meteorological effects of these changes. The MM5 is a numerical model, used worldwide, which is one of the main tools of the Hungarian nowcasting system too. The lower boundary conditions for this mesoscale model were generated for two selected time periods (for 1900 and 2000) based on the reconstructed maps (Fig.2). The horizontal resolution of the numerical model was 2.5 km in each case.

Table 1. The pre-defined macro synoptic situations for Hungary, their long term (1961-1990) mean frequency (during the time period from April to September) and the dates of the model runs

Pre-defined Macro-synoptic Situations for Hungary (Péczely, 1983).	Mean Frequency	Selected Dates
The weather in Hungary is determined by:		
((mCc)) the back of cyclone (possibly its cold front)	8.77%	28th Aug, 2006 , 00 UTC + 48h 5th July, 2007 , 00 UTC + 48h
((AB)) the anticyclone over the British Isles (or North Sea)	7.97%	13th July, 2006 , 00 UTC + 48h 9th April, 2007 , 00 UTC + 48h
((CMc)) the back of a Mediterranean cyclone (possibly its cold front)	3.40%	10th April, 2006 , 00 UTC + 48h 9th Aug, 2007 , 00 UTC + 48h
((mCw)) the front side of cyclone (possibly its warm front)	8.90%	18th June, 2006 , 00 UTC + 48h 21st Aug, 2007 , 00 UTC + 48h
((Ae)) the cyclone that is on the east from the country	9.12%	5th July, 2006 , 00 UTC + 48h 29th Sept, 2007 , 00 UTC + 48h
((CMw)) the fore side of Mediterranean cyclone (possibly its warm front)	6.42%	5th April, 2006 , 00 UTC + 48h 4th May, 2007 , 00 UTC + 48h
((zC)) the zonal stream of the cyclone that is north of the country	3.48%	19th May, 2006 , 00 UTC + 48h 8th May, 2007 , 00 UTC + 48h
((Aw)) the anticyclone that is west of the country	17.75%	21st Aug, 2006 , 00 UTC + 48h 29th June, 2007 , 00 UTC + 48h
((As)) the zonal stream of the anticyclone that is south of the country	3.55%	2nd Sept, 2006 , 00 UTC + 48h 13th July, 2007 , 00 UTC + 48h
((An)) the anticyclone that is north of the country	12.62%	29th June, 2006 , 00 UTC + 48h 4th June, 2007 , 00 UTC + 48h
((AF)) the anticyclone over Scandinavia	4.47%	9th June, 2006 , 00 UTC + 48h 14th April, 2007 , 00 UTC + 48h
((A)) the anticyclone over Hungary	10.67%	10th Sept, 2006 , 00 UTC + 48h 20th Sept, 2007 , 00 UTC + 48h
((C)) the cyclone over Hungary	2.90%	30th May, 2006 , 00 UTC + 48h 11th Aug, 2007 , 00 UTC + 48h

3.3 Stratified Sampling

The dynamic model was run with the same detailed meteorological conditions of selected days from 2006 and 2007, but with modified lower boundary conditions. The macro-synoptic type had to remain unchanged for at least 48 hours. The dates of the model runs were selected evenly within the six months of the vegetation period, (April to September). The set of 2×13 selected initial conditions represents the whole set of the macro synoptic situations for Hungary (Péczely, 1983; Table 1). 52 ($2 \times 2 \times 13$) forecasts were made with 48 hours of integration. The effects of land cover changes under the different weather situations were further weighted by the long-term (1961-1990) mean frequency of the corresponding macro synoptic types, to estimate the climatic effect with these stratified averages. This process is called *stratified sampling*.

4 RESULTS

The short summary of results was taken nation-wide for three climate variables (temperature (2m), dew-point depression (2m), and precipitation). According to the comparisons, climatic effects of the land cover changes on the meteorological variables near the surface were not negligible during the 1900s. On average nation-wide, they caused +0.15 °C temperature increase and a 0.18 °C increase in the dew-point depression during the vegetation period. The temperature difference has three well-defined maxima in the night hours (Fig.3). This is a consequence of the urban heat island phenomenon whose effect is strongest at night. The changes are most profound in those parts of the country where urbanisation was highest. For example, within the current borders of Budapest, the land cover change caused an average 1.2 °C increase in daily temperature during the vegetation period.

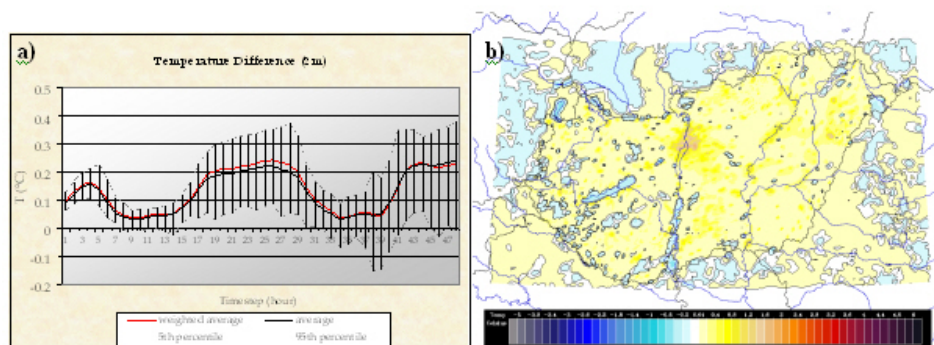


Figure 3. The temporal (a) and spatial (b) distribution of temperature changes due to the Hungarian land cover changes during the 20th century after applying the stratified sampling method. The 12th and 36th hours correspond to 2 p.m. local time.

Fig. 3b also shows that in a few places in the country, contrary trends were found from the national mean. Both the temperature and the dew-point changes (not shown) are the most expressed within the country's borders, because only the land cover changes within the country were available. Nevertheless, some effects of these changes within the country are also obvious outside the borders. Similar changes in the neighbouring countries, not involved into our simulations, could also affect the climate of Hungary.

Fig. 4 shows that according to the simulations, the two different lower boundary conditions did not cause significant changes in the total precipitation over Hungary. After applying stratified sampling, the simulated mean precipitation was around 6 mm during the 48 hour periods (5.95 mm with the land cover in 1900, 6.01 mm with the land cover in 2000). Nevertheless, by the analysing the spatial distribution of precipitation differences (Fig. 4b), we concluded that there are many regions where more than ± 7 mm precipitation anomalies were emerging in consequence of different land cover datasets. This means that the local uncertainty of precipitation forecast due to historical land cover changes exceeds the mean amount of the predicted total precipitation. Consequently we need an accurate description of current land cover in the modelling system to get correct precipitation forecasts.

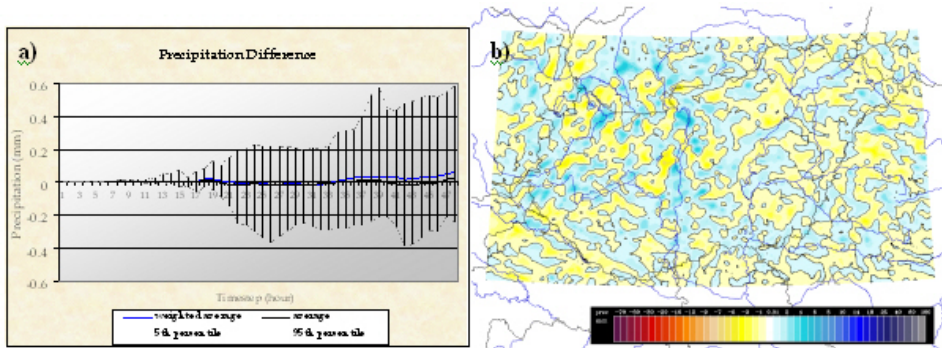


Figure 4. Effects of historical land cover changes on the area mean precipitation (a) and on the precipitation distribution (b) over Hungary after applying stratified sampling. The MM5 was integrated for 48 hours in all cases. The largest differences caused by the land cover changes exceed ± 7 mm/48 hours.

In certain cases the historical land cover changes could dramatically affect the local precipitation intensity and distribution. In particular cases this effect is connected with the phenomena that the emergence of a thunderstorm is also influenced by “minor” effects, such as temperature deviations over different land cover categories. We found that the simulated precipitation falls in a different regional distribution due to the varying lower boundary conditions, although the meteorological conditions were the same. We illustrate this phenomenon through analysing one selected weather situation.

In our selected case, (11th August, 2007), during the running hours, there was a cyclone with its centre over Hungary. The simulated total precipitation was around 17 mm nation-wide. There were only small differences in this mean amount depending on which land cover was used during the simulations.

Applying the 1900 land cover, the forecasted total precipitation inside the borders was 17.8 mm; while using the 2000 land cover, it was 16.5 mm precipitation. Despite the small differences in these mean values (Fig.5a), the impact of land cover changes on local precipitation in some regions exceeds 40 mm during the simulated 2 day time period as shown in Fig.5b.

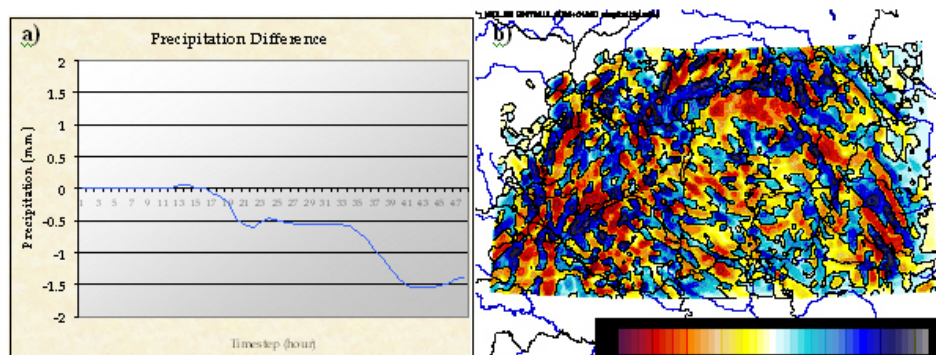


Figure 5. Effects of historical land cover changes on the area mean precipitation (a) and on the precipitation distribution (b) over Hungary as simulated for a (C) situation with a temperate latitude cyclone with its centre over Hungary, initialized at 00 UTC on 11th August, 2007. The MM5 was integrated for 48 hours, as in all other cases. The largest differences caused by the land cover changes exceed ± 40 mm/48 hours.

The odd thing about this situation is that the effect of the Tisza Reservoir on the precipitation intensity becomes visible between the 27th and 29th running hours (Fig.6). These selected hours clearly demonstrate how land cover changes can cause locally significant differences in predicted precipitation. By using a 1900 land cover only 1-2 mm precipitation was predicted for the region of the present reservoir (local time between 3 a.m. and 6 a.m.), because the reservoir did not yet exist at the beginning of the 20th century. By using 2000 land cover, the large water body of the present reservoir functioned as a great source of heat and moisture for the air at night. Therefore, the model simulated heavy showers over the reservoir during the same 3 hour time interval.

These results clearly show that the large-scale weather conditions were unstable in this region at that time, but the essential heat for intensive convection producing local precipitation was available only in around the existing reservoir. Due to this fact, a heavy rainstorm appeared only in the simulation with present land cover datasets.

It should be noted that the meteorological effect of Tisza Reservoir varies between day and night. Contrary to the warming effect at night, water bodies usually cool the air near the surface in the day time.

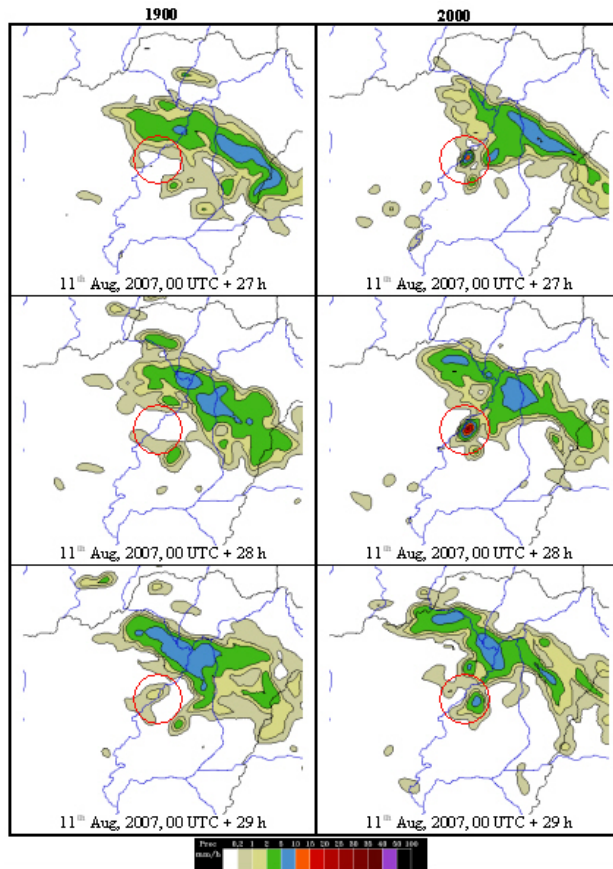


Figure 6. Effects of Tisza Reservoir on the local precipitation intensity as simulated for a (C) situation with a temperate latitude cyclone with its centre over Hungary initialized at 00 UTC on 11th August, 2007. The differences between the first and second column were caused by the different lower boundary conditions.

5 CONCLUDING REMARKS

After the analysis of MM5 dynamic model simulations, we found that the Hungarian land cover changes in the last 100 years caused an increase of $+0.15^{\circ}\text{C}$ daily temperature and $+0.18^{\circ}\text{C}$ dew-point depression during the vegetation period. This means that the near-surface air over Hungary is now warmer and drier than before due to the land cover change. It is also plausible, that the computed results show the maximum warming and drying over the urban areas. After the comparison of the warming effect of the land cover change with the documented warming in Hungary we concluded that the climatic effects of land cover changes are not negligible. Consequently, beyond other climate forcing processes, it is necessary to take land cover change into account by the interpretation of climate change in the past and for making scenarios for the future.

Since the climatic effects of Hungarian land cover change are based on 26 weather conditions only, the averaged results may be uncertain due to the relatively few samples of meteorological cases. Nevertheless we conclude that the increase of the daily temperature likely exceeds $+0.1^{\circ}\text{C}$, since all types exhibited warming between the 1900 vs. 2000 land cover types, and the increase was larger or equal to 0.1°C in 19 of the 26 situations. The stratified sampling may not be as accurate as the true climatic average from long-term observations, but the order of magnitude in our estimations is probably correct.

It was also proven that the Hungarian land cover change does not have a significant impact on the average precipitation nation-wide. However, the impact on the regional distribution of precipitation is considerable, especially under unstable weather conditions. The present study clearly shows that MM5 precipitation forecast is very sensitive to the lower boundary conditions. (All other mesoscale models must also be sensitive). Since the Hungarian Nowcasting System uses the MM5 and WRF models, which work with the same land surface model, it would be reasonable to update the land cover database of these models by using current land cover maps. In addition, it is also necessary to update the land cover parameters of these models. The quality of the weather forecasting would be considerably improved.

6 RELATED WEBSITES, PROJECTS AND VIDEOS

Land use, land use change and forestry:

<http://forest.jrc.ec.europa.eu/activities/lulucf/>

IPCC special report on forests: http://www.ipcc.ch/ipccreports/sres/land_use/index.php?idp=0

<http://unfccc.int/methods/lulucf/items/4122.php>

http://ec.europa.eu/clima/policies/forests/lulucf/index_en.htm

http://en.wikipedia.org/wiki/Land_use,_land-use_change_and_forestry

Good Practice Guidance for Land Use, Land-Use Change and Forestry: [HTTP://WWW.IPCC-NGGIP.IGES.OR.JP/PUBLIC/GPGLULUCF/GPGLULUCF.HTML](http://www.ipcc-nggip.iges.or.jp/public/gpoglulucf/gpoglulucf.html)

REFERENCES

- Avissar, R., and R. A. Pielke, 1989: A parameterization of heterogeneous land surface for atmospheric numerical models and its impact on regional meteorology, *Mon. Wea. Rev.*, 117: 2113-2136
- Bedő, A. (1896), Synoptic Forestry Map of the Kingdom of Hungary, Bp. 1896.
- Beringer, J., F. S. Chapin, C. Thompson, and A. D. McGuire, 2005: Surface energy exchanges along a tundra-forest transition and feedbacks to climate, *Agricultural and Forest Meteorology*, 131: 142-161
- Bertrand C., France Loutre M., Crucifix M., and Berger A., 2002: Climate of the last millenium: a sensitivity study. *Tellus 54A*: 221-244
- Betts R.A., 2006: Forcings and feedbacks by land ecosystem changes on climate, *Journal de Physique IV*, 139: 123-146
- Bonan, G. B., 2004: Biogeophysical feedbacks between land cover and climate, *Ecosystem and Land Use Change*: 61-72
- Bonan, G., 2002: *Ecological Climatology: Concepts and Applications*. Cambridge University Press, 678 pp.
- Brovkin, V., Sitch, S., von Bloh, W., Claussen, M., Bauer, E., Cramer, W., 2004: Role of land cover changes for atmospheric CO₂ increase and climate change during the last 150 years. *Global Change Biol.* 10:1253-1266
- Budyko, M. I., 1974: *Climate and Life*. Academic Press, 608 pp.
- Chagnon, F. J. F., and Bras, R. L., 2005. Contemporary climate change in the Amazon. *Geophysical Research Letters* 32: L13703
- Charney, J. G., 1975: The dynamics of deserts and droughts, *Quart. J. Roy. Meteor. Soc.* 101: 193-202

- Charney, J. G., W. J. Quirk, S. H. Chow, and J. Kornfield, 1977: A comparative study of the effects of albedo change on drought in semiarid regions, *J. Atmos. Sci.* 34: 1366-1385
- Chase, T. N., R. A. Pielke Sr., T. G. F. Kittel, J. S. Baron, T. J. Stohlgren, 1999: Potential impacts on Colorado Rocky Mountain weather due to land use changes on the adjacent Great Plains, *J. Geophys. Res.* 104: 16673-16690
- Chen, F., and R. Avissar, 1994: The impact of land surface wetness heterogeneity on mesoscale heat fluxes, *J. Appl. Meteor.* 33: 1323-1340
- Clark, B.D., Xue, Y., Harding, R.J., and P. J. Valdes, 2001: Modeling the impact of land surface degradation on the climate of tropical North Africa. *J. Climate* 14: 1809-1822
- CORINE, 2000: Corine land cover 2000 (CLC2000) seamless vector database, <http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database>
- Crutzen PJ, 2002: Geology of mankind – the Anthropocene, *Nature* 415: 23
- Drüsler, Á., Vig, P., and Csirmaz, K., 2011: Impacts of Hungarian Land Cover Changes on the Regional Climate during the 20th Century; *XXVth Conference of the Danubian Countries, Budapest, Hungary*, 16-17 June 2011
- Drüsler, Á., Csirmaz, K., Vig, P., and J. Mika 2010: Effects of documented land use changes on temperature and humidity regime in Hungary; *In: S. P. Saikia 2010: Climate Change*, International Book Distributors, ISBN: 81-7089-370-4: 394-418
- Frankignoul, C., and E. Kestenare, 2002: The surface heat flux feedback, Part I: Estimates from observations in the Atlantic and the North Pacific. *Climate Dyn.*, 19, 622–647.
- Frankignoul, C., A. Czaja, and B. L'Heveder, 1998: Air–sea feedback in the North Atlantic and surface boundary conditions for ocean models. *J. Climate*, 11, 2310–2324
- Gash, J. H. C., C. A. Nobre, J. M. Roberts, and R. L. Victoria (Eds.), 1996: Amazonian Deforestation and Climate, 611 pp., John Wiley, N.Y.
- Gash, J. H. C, and C. A. Nobre, 1997: Climate effects of Amazonian Deforestation: some results from ABRACOS, *Bull. Amer. Meteor. Soc.* 78: 823-830
- Grell, G.A., J. Dudhia and D.R. Stauffer, 1994: A description of the 5th generation Penn State/NCAR Mesoscale model (MM5). *NCAR technical note, NCAR/TN-398+STR*, 117 pp, 122.
- Houghton, R., 2003: Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850-2000. *Tellus* 55B: 379-390
- IPCC, 2001: Climate Change 2001: *The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental panel on Climate Change* (Houghton J.T., et al., eds.), Cambridge University. Press, Cambridge, United Kingdom and New York, USA, 881 p.<
<http://www.ipcc.ch>>: Chapter 6, 399. pp.
- IPCC, 2007: Climate Change 2007: *The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.
- Kleidon, A., and M. Heimann, 2000: Assessing the role of deep rooted vegetation in the climate system with model simulations: mechanism, comparison to observations and implications for Amazonian deforestation, *Clim. Dyn.* 14: 183-199
- Klein Goldewijk K, 2001: Estimating global land use change over the past 300 years: The HYDE database, *Global Biogeochem Cy* 15: 417-434
- Lean, J., and P. R. Rowntree, 1997: Understanding the sensitivity of a GCM simulation of Amazonian deforestation to the specification of vegetation and soil characteristics , *J. Climate* 10: 1216-1235

- Liu, Z., M. Notaro, J. Kutzbach, and N. Liu, 2006: Assessing global vegetation–climate feedbacks from observations. *J. Climate*, 19, 787–814.
- Matthews, H.D., Weaver, A.J., Meissner, K.J., Gillett, N.P., Eby, M., 2004: Natural and anthropogenic climate change: incorporating historical land cover change, vegetation dynamics and the global carbon cycle. *Clim Dyn* 22: 461–479
- Matthews, H.D., Weaver, A.J., Eby, M., and K.J., Meissner, 2003: Radiative forcing of climate by historical land cover change. *Geophys. Res Lett.* 30:27-1–27-4
- Mika, J., Horváth Sz. and Makra L., 2006: Effects of documented land use changes on the albedo of Eastern Hungary (1951–2000), *Időjárás* 110: 49–62
- MMS, 1910: 3rd Military Mapping Survey of Austria-Hungary, published about 1910, <http://lazarus.elte.hu/hun/digkonyv/topo/3felmeres.htm>
- Nemani, R. R., C. D. Keeling, H. Hashimoto, W. M. Jolly, S. C. Piper, C. J. Tucker, R. B. Myneni, and S. W. Running, 2003: Climate-driven increases in global terrestrial net primary production from 1982 to 1999. *Science*, 300, 1560–1563
- Notaro, M., Z. Liu, and J. Williams, 2006: Observed vegetation–climate feedback in the United States. *J. Climate*, 19, 763–786.
- Péczely Gy., 1983: Catalogue of macrosynoptic types in Hungary (1881–1983). Minor Contributions of the Hungarian Meteorological Service, Budapest, vol. 53 (*in Hungarian*)
- Pielke RA, Lee TJ, Copeland JH, Eastman JL, Ziegler CL, Finley CA, 1997: Use of USGS-provided data to improve weather and climate simulations, *Ecol. Appl.* 7: 3–21
- Pielke, R., R. Avissar, M. Raupach, A. J. Dolman, X. Zhen, and A. S. Denning, 1998: Interactions between the atmosphere and terrestrial ecosystems: Influence on weather and climate. *Global Change Biol.*, 4, 461–475
- Prentice, I. C., 2001: Interactions of climate change and the terrestrial biosphere. *Geosphere–Biosphere Interactions and Climate*, L. O. Bengtsson and C. U. Hammer, Eds., Cambridge University Press, 176–195
- Ramankutty, N., and Foley JA, 1998: Characterising patterns of Global land use: An analysis of global cropland data, *Global Biogeochem. Cy.* 12: 667–685
- Roy, S., and Avissar R., 2002: Impact of land use/land cover change on regional hydrometeorology in Amazonia, *J. Geophys. Res.*, 107(D20), 8037
- Shaw BL, Pielke RA, Ziegler CL, 1997: A three-dimensional numerical simulation of a Great Plains dryline, *Mon. Weather Rev.* 125: 1489–1506
- Thomas, G., and P. R. Rowntree, 1992: The boreal forests and climate, *Quart. J. Roy. Meteor. Soc.* 118: 469–497
- Xue, Y., and J. Shukla, 1993: The influence of land surface properties on Sahel climate. Part I: Desertification, *J. Clim.* 6: 2232–2245

Afforestation as a tool for climate change mitigation

Borbála Gálos

ABSTRACT

This chapter introduces the results of regional-scale sensitivity studies carried out to investigate the role of afforestation in climate change mitigation for Europe. Applying the regional climate model REMO, the projected temperature and precipitation tendencies have been analyzed for summer, based on the results of the A2 IPCC-SRES emission scenario simulation. For the end of the 21st century it has been studied, whether the increased forest cover could reduce the effects of the enhanced greenhouse gas emission. The magnitude of the biogeophysical effects of afforestation on temperature and precipitation has been determined relative to the magnitude of the climate change signal. Based on the simulation results, afforestation may lead to cooler and moister conditions in most parts of the temperate zone thus can reduce the projected climate change. The largest relative effects of afforestation can be expected in northern Germany, Poland and Ukraine, which is 15-20 % of the climate change signal for temperature and more than 50 % for precipitation. The possible climate change mitigating effect of afforestation shows large differences among regions, which have been analyzed for Hungary more in detail. Results can help to identify the areas, where forest cover increase is the most favourable and should be supported to reduce the projected climate change. They can build important basis of the future adaptation strategies and forest policy.

1 INTRODUCTION

1.1 Regional climate projections for Europe

Several natural and anthropogenic processes influence the climate of the Earth. Human affect climate through increasing greenhouse gas concentrations, changing aerosol compositions as well as by land surface changes (IPCC, 2007). There are several recent EU-projects carried out in the last decade, to provide high-resolution climate change projections with focus on future climate changes and their impacts in Europe (Christensen et al., 2007; Jacob et al., 2008; van der Linden & Mitchell, 2009). These studies are based on the results of regional climate model simulations driven by different predefined greenhouse gas emission scenarios. The difference between the simulated climatic conditions for the future and for the present time period is the climate change signal. For the 21st century, projected climate change signals for temperature and precipitation show seasonal and spatial differences in Europe and also vary depending on the applied greenhouse gas emission scenario.

For the period 2021-2050 all regional climate models predict a quite robust surface warming in central and eastern Europe. The annual precipitation shows an increase in the northeastern and a decrease in the southwestern regions. (Christensen & Christensen, 2007; Kjellström et al., 2011). At the end of the 21st century, a warming is expected in all seasons over Europe, which is stronger than in the first half of the 21st century. All models agree that the largest warming for summer is projected to occur in the Mediterranean area, southern France and over the Iberian Peninsula. Less warming is projected over the Scandinavian regions. For winter the maximum warming occurs in eastern Europe (Christensen & Christensen, 2007). Results of the regional model simulations show a north-south gradient of annual precipitation changes over Europe, with positive changes in the north (especially in winter) and negative changes in the south (especially over the Mediterranean area in summer). For southern and central Europe the spatial distribution of the projected temperature and precipitation changes in summer refer to a marked shift towards a warmer and drier climate (e.g. Beniston, 2009).

1.2 Climatic effects of land use and land cover change

Temperature and precipitation play an important role in determining the distribution of the terrestrial ecosystems that in turn interact with the atmosphere through biogeophysical and biogeochemical processes. Vegetation affects the physical characteristics of the land surface, which control the surface energy fluxes and hydrological cycle (biogeophysical feedbacks; Pielke et al., 1998; Pitman, 2003). Through biogeochemical effects, ecosystems alter the biogeochemical cycles, thereby change the chemical composition of the atmosphere (Bonan, 2002; Pitman, 2003; Feddema et al., 2005). Forests have larger leaf areas and aerodynamic roughness lengths, lower albedo and deeper roots compared to other vegetated surfaces. They sequester carbon thereby alter the carbon storage of land.

Depending on the region, biogeophysical and biogeochemical feedbacks of land cover on climate can amplify or dampen each other (Arora & Montenegro, 2011). Through these land-atmosphere interactions changes of the land cover and land use due to natural and human influence alter climate and hence can lead to the enhancement or reduction of the projected climate change signals expected from increased atmospheric CO₂ concentration (Feddema et al., 2005; Bonan, 2008).

This section focuses on studies of the biogeophysical processes, which represent the contrasting climatic effects of forest cover changes on different regions, seasons and time scales. Changes of vegetation cover under future climate conditions enhance the warming trend in Scandinavian Mountains as well as the drying trend in southern Europe, but mitigate the projected increase of temperature in central Europe (Wramneby et al., 2010). Boreal forests have the greatest biogeophysical effect of all biomes on annual mean global temperature, which is larger than their effect on the carbon cycle (Bonan, 2008). If snow is present, the darker coniferous forest masks the snow cover. It is resulting in lower surface albedo compared to tundra vegetation or bare ground, which leads to higher winter and spring air temperatures (Bonan et al., 1992; Kleidon et al., 2007). Consequently, the change of vegetation from tundra to taiga under future climate conditions amplifies the global warming. Tropical forests maintain high rates of evapotranspiration. In this region, surface warming arising from the low albedo of forests is offset by the strong evaporative cooling that reduces global temperature increase (Bonan, 2008).

In temperate forests the albedo and evaporative forcings are moderate compared with boreal and tropical forests (Bonan, 2008; Jackson et al., 2008). Climate model studies for the temperate regions showed that replacing forests with agriculture or grasslands reduces the surface air temperatures (Bounoua et al., 2002; Oleson et al., 2004) and the number of summer hot days (Anav et al., 2010). Other studies show opposite results, where temperate forests cool the air compared to grasslands and croplands and contribute to higher precipitation rates in the growing season (Hogg et al., 2000; Sánchez et al., 2007, Gálos et al., 2011; 2012; 2013). In the Mediterranean region climatic effects of forest cover change can also vary during the summer months (Heck et al., 2001). In the period from April until mid-July potential vegetation cover conditions led to cooler and moister conditions due to the increase of evapotranspiration. In mid-July soil moisture dropped below the critical value and transpiration was almost completely inhibited. It resulted in dryer and warmer summer accelerating the projected climate change. Teuling et al. (2010) pointed out that the role of the forests in the surface energy and water budget is depending on the selected time scale: in the short term, forests contribute to the increase of temperature, but on longer time scales they can reduce the impact of extreme heat waves.

These studies indicate that forests can enhance or dampen the climate change signal depending on various contrasting vegetation feedbacks, which can diminish or counteract each other. Furthermore the variability of the climatic, soil and vegetation characteristics as well as as well as the description of the land surface processes in the applied climate model also have an influence on the simulated vegetation-atmosphere interactions.

1.3 Research foci

The climatic feedbacks of land cover changes due to climate change and the regional land use politics as well as the role of the forests in the climate change mitigation on country scale are still unknown. In order to address this topic, our sensitivity study is focusing on the climatic effects of afforestation in Europe under future climate conditions based on the following research questions:

- In which regions does the increase of forest cover enhance/reduce the projected climate change?

- How big are the effects of forest cover change on the summer precipitation and temperature relative to the climate change signal?
- Which are the regions, where afforestation is the most beneficial from a climatic point of view?

On country scale, a more detailed case study has been carried out for Hungary. For the end of the 21st century, regional climate model simulations project a significant increase of summer temperature and a decrease of summer precipitation (Bartholy et al., 2007; Gálos et al., 2007). From ecological point of view Hungary (in the southeastern part of central Europe) has been selected as study region because here, many of the zonal tree species have their lower limit of distribution (Mátyás et al., 2009), which are especially sensitive and vulnerable to the increase of the frequency of climatic extremes, primarily to droughts. In these forests the more frequent and severe droughts at the end of the 20th century already resulted in growth decline, loss of vitality and the decrease of the macroclimatically suitable area of distribution (Berki et al., 2009). Under the projected climate conditions these species may disappear from this region (Berki et al., 2009; Mátyás et al., 2010; Czúcz et al., 2011). In the last 50 years, large scale afforestation was carried out in Hungary, which is planned to continue also in the near future. The influence of the historical land cover change on weather and climate has been investigated by Drüzler et al. (2011). For the future, forests can also have an important role in climate change mitigation. Therefore this case study is concentrating on the possible mitigation of the strong warming and drying of summers projected for the second half of the 21st century.

2 METHODS

Regional climate models have the potential to provide detailed information about the future climate on fine horizontal resolution. For studying the climatic feedbacks of land cover change in Europe regional scale analyses are essential because of the differences in the climate sensitivity among regions and the large spatial variability of the land surface properties and the related processes.

2.1 Experimental setup

In this study the REgional climate MOdel (REMO) has been applied for Europe, with horizontal resolution 0.22° . REMO (Jacob et al., 2007) is a regional three-dimensional numerical model of the atmosphere. Land surface processes in REMO are controlled by physical vegetation properties (like of leaf area index, fractional vegetation cover for the growing and dormancy season, background albedo, surface roughness length due to vegetation, forest ratio, plant-available soil water holding capacity and volumetric wilting point; Hagemann et al., 1999; Hagemann, 2002; Rechid & Jacob, 2006; Rechid et al., 2008a, 2008b). Land cover change in REMO can be implemented by modification of the characteristic land surface parameters.

Table 1. Analyzed data and time periods

Experiment	Reference simulation	Potential afforestation simulation
Characteristics	Present forest cover	Afforestation over all vegetated area ^a
Time period	1971-1990 2071-2090	2071-2090
Greenhouse gas forcing	IPCC-SRES emission scenario A2	
Horizontal resolution	0.22°	
Lateral boundaries	ECHAM5/MPI-OM ^b	

^a based on Kindermann (pers. comm.)

^b Roeckner et al., 2006; Jungclaus et al., 2006

The following experiments have been performed (table 1):

- *Reference simulation* for the past (1971-1990) with present (unchanged) forest cover.
- *Emission scenario simulation* for the future (2071-2090) with present (unchanged) forest cover applying the A2 IPCC-SRES emission scenario (Nakicenovic et al., 2000).
- *Potential afforestation* experiment for 2071-2090. The forest cover increase (figure 1) is based on the net primary production map for Europe derived from remotely sensed MODIS (Moderate-Resolution Imaging Spectroradiometer) products, precipitation and temperature conditions from the Wordclim database and soil conditions from the International Institute for Applied Systems Analysis (Kindermann, pers. comm.). The new afforested areas were assumed to be deciduous.

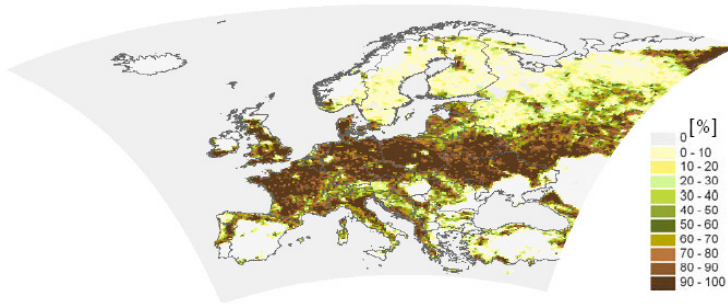


Figure 1. Increase of the forest cover in the potential afforestation simulation compared to the present (unchanged) forested area in the model (Gálos et al. 2012)

2.2 Main steps of the analyses

These analyses are focusing on the biogeophysical feedbacks of afforestation on the climate. Simulation results have been analyzed for May, June, July and August. In this study the mean of this period is considered 'summer' (MJJJ), because in these months water availability is especially important for the vegetation growth. The leaf area index of the deciduous forests reaches its maximum, which has a strong control on the land-atmosphere interactions.

- *Climate change due to changes in emissions* has been investigated analyzing the summer precipitation sums and 2m-temperature means for 2071-2090 (without any land cover changes) compared to 1971-1990.
- *Climate changes due to potential afforestation* has been calculated comparing the simulation results with- and without forest cover increase for the future time period (2071-2090).
- *Climate changes due to emission change and potential afforestation* have been determined comparing the results of the potential afforestation experiment (2071-2090) to the reference study in the past (1971-1990). The sign and the magnitude climatic effects of potential afforestation have been analyzed relative to the climate change signal.

For more detailed analyses, a case study has been prepared for Hungary over a smaller simulation domain, applying the same regional climate model and the same steps for data analyses. To get information about the maximum climatic effects of afforestation and its regional differences, the whole vegetated area of Hungary was assumed to be forest and the new afforested areas are all deciduous. The assumed maximal afforestation takes approximately 75 % increase of forest cover in country mean additionally to the existing 20 % forested area (figure 2).

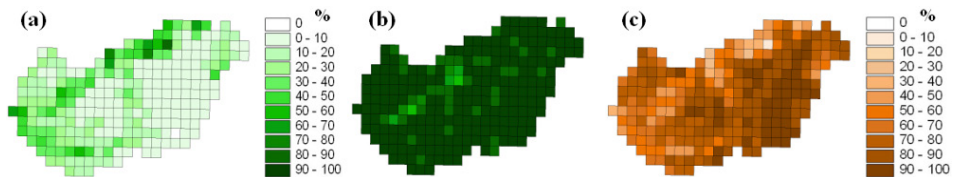


Figure 2. Forest cover in Hungary in the reference simulation (a) and in the maximal afforestation experiment (b). Increase of forest cover in the maximal afforestation experiment compared to the reference (c). Adapted from: Gálos et al., 2011

3 RESULTS

Simulation results of the sensitivity studies can be summarized as follows:

3.1 Climate change signal due to emission change (figure 3a):

- *Sign of the effects:* For the A2 emission scenario, a positive temperature signal is expected in whole Europe, which is projected to occur together with precipitation decrease in southern and central Europe and in the southern part of Scandinavia.
- *Magnitude of the effects:* The strongest warming and drying are projected for the Mediterranean area, southern France and over the Iberian Peninsula.

3.2 Climate change signal due to potential afforestation (figure 3b):

- *Sign of the effects:* In most parts of the temperate zone the cooling and moistening effect of afforestation dominates. Portugal, the Mediterranean coasts and the southern part of the boreal zone show a shift into the warmer and wetter direction. Warmer and dryer conditions over larger areas may occur in the boreal region.
- *Magnitude of the effects:* Afforestation has the largest climatic effects in the northern part of central and western Europe, where the temperature decrease due to afforestation may exceed 0.3 °C additionally to more than 10 % increase of the summer precipitation sum.

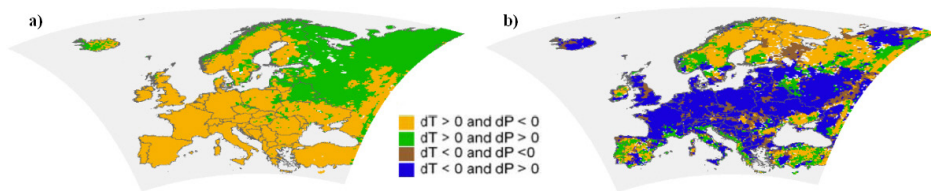


Figure 3. Climate change signal for temperature (dT) and precipitation (dP) due to emission change (a) and due to potential afforestation (b). Adapted from: Gálos et al., 2012

3.3 Climate change signal due to potential afforestation relative to the emission change (figure 4):

- *Sign of the effects:* In the largest part of the temperate zone precipitation and temperature anomalies due to forest cover increase show the opposite sign than due to emission change, which means that the climate change signal can be reduced by afforestation. Whereas in Sweden, in Spain and in some regions in the eastern part of the continent afforestation can amplify the climate change signal for both investigated variables.

- *Magnitude of the effects:* The largest climate change mitigating effects of afforestation can be expected in northern Germany, Poland and Ukraine, which is 15-20 % of the climate change signal for temperature and more than 50 % for precipitation. These changes are significant at the 90 % confidence level.

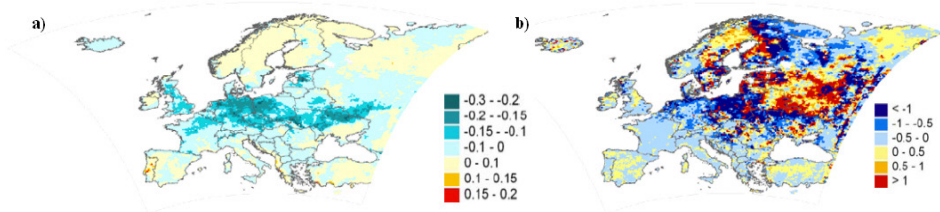


Figure 4. Climate change signal due to potential afforestation divided by the climate change signal due to emission change for temperature (a) and precipitation (b). The reddish colours are referring to the areas, where the changes of the analyzed climatic variables have the same sign for both afforestation and emission change. Whereas in the regions marked with bluish colours they show opposite sign. Adapted from: Gálos et al., 2012

3.4 Case study for Hungary (figure 5):

- *Sign of the effects:* The projected climate change signal for precipitation can be reduced assuming maximal afforestation.
- *Magnitude of the effects:* The strong warming and drying tendency projected for Southwest Hungary could be hardly compensated by forest cover increase. But in the northwestern region more than half of the projected climate change signal for precipitation can be relieved with enhanced forest cover.