

Biodiversity and Climate Change: Consequences for Norway Spruce Mountain Forests in Slovakia

Jozef Mindas, Jaroslav Skvarenina, Jana Skvareninova

Abstract—Study of the effects of climate change on Norway Spruce (*Picea abies*) forests has mainly focused on the diversity of tree species diversity of tree species as a result of the ability of species to tolerate temperature and moisture changes as well as some effects of disturbance regime changes. The tree species' diversity changes in spruce forests due to climate change have been analyzed via gap model. Forest gap model is a dynamic model for calculation basic characteristics of individual forest trees. Input ecological data for model calculations have been taken from the permanent research plots located in primeval forests in mountainous regions in Slovakia. The results of regional scenarios of the climatic change for the territory of Slovakia have been used, from which the values are according to the CGCM3.1 (global) model, KNMI and MPI (regional) models. Model results for conditions of the climate change scenarios suggest a shift of the upper forest limit to the region of the present subalpine zone, in supramontane zone. N. spruce representation will decrease at the expense of beech and precious broadleaved species (*Acer* sp., *Sorbus* sp., *Fraxinus* sp.). The most significant tree species diversity changes have been identified for the upper tree line and current belt of dwarf pine (*Pinus mugo*) occurrence. The results have been also discussed in relation to most important disturbances (wind storms, snow and ice storms) and phenological changes which consequences are little known. Special discussion is focused on biomass production changes in relation to carbon storage diversity in different carbon pools.

Keywords—Biodiversity, climate change, Norway spruce forests, gap model.

I. INTRODUCTION

OVER the last two centuries, Norway spruce (*Picea abies* (L.) Karst.) became the most spread commercial tree species in the western and central-eastern Europe. A relatively simple cultivation, fast growth, high production, wide utilization of its wood, need for afforestation of non-forest land in connection with the endeavour to reach the highest possible yield have led to such a fact that spruce cultivation has spread even beyond its original (mountain) range, mainly to lower locations, even lowlands. According to data from [11], present proportion of Norway spruce (cca 23.7%) in tree species composition of the forests of Slovakia differs pronouncedly from its original representation (cca 8%).

Forests are particularly sensitive to climate change, because the long life-span of trees does not allow for rapid adaptation to environmental changes. Associated with climate change there are several factors affecting forest ecosystems, which

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can act independently or in combination. Two decades of research have significantly improved our understanding of these basic impact factors [3], [10].

Since 1996, we can identify five periods with higher levels of incidental felling in Slovakia. It was around 1990, 1995-1997, 2000, 2008-2010, and 2014. High incidental felling preceded the events that directly damage the forest or reduce its defenses. The first two periods are related to the drought, the third period of drought and wind, and the fourth and fifth ones with the wind. After each damaged stands followed by abiotic factors infestation of bark beetles in Norway spruce stands [11].

In Slovakia, as the last 25 years has given several 10,000 hectares of calamity areas mainly in mountain forests (over 800 m a.s.l.) of the Northern and Central part of Slovakia. On the one hand it is a serious ecological and environmental problem in terms of functional effect of mountain forests, on the other hand, it poses a challenge in terms of adaptation measures towards a change in the species composition of mountain forests and thus to secure their future functional effect under the climate change conditions [11].

The aim of this work is to analyze the impacts of climate change on mountain spruce forests in terms of biodiversity using the Forest Gap model and regression models selected indices of biodiversity. The priority goal is to obtain a set of knowledge that could be applied in the reconstruction of calamity areas in the mountain forests of Slovakia.

II. METHODOLOGY

A. Forest Gap Model

Forest gap models are included into a group of dynamic models which are able to calculate various characteristics of forest trees in time series. Gap models are individually based in that they simulate establishment, growth, and mortality of each tree on the forest plot [4]. The response of an individual tree to ecological conditions on the plot are defined by a number of environmental response functions, generally expressed as a portion of optimal growth, ranging from 0.0 to 1.0. These environmental response functions have been defined by using various methods. A detailed discussion and theoretical basis of these methods can be found in [1], [4].

The model requires the following input data for individual trees: Maximum tree age, maximum diameter, maximum height, and maximum yearly seedling establishment scaled to plot. This model contains several „response functions“ including light, water balance, and climate responses of individual trees, which are described in [6].

Necessary input parameters for the calculation were

obtained from long-term observations of primeval forests in Slovakia e.g. [5].

Model calculations of Gap model were carried out for two sites with different altitude. The first location at an altitude of 1300 m a.s.l. is characterized by the occurrence of mixed mountain forests with occurrence of *Picea abies*, *Fagus sylvatica* and *Abies alba*, with addition of *Acer* and *Fraxinus* species. The second location at an altitude of 1700 m a.s.l. is located above the current upper limit of the forest and is characterized by the occurrence of mountain (dwarf) pine (*Pinus mugo*) with an admixture of *Picea abies* and *Sorbus aucuparia* in a stunted form.

B. Biodiversity Indices

Biodiversity analysis was performed based on model calculations for two diversity indices: Shannon's index and Hill index, which proved to be the most appropriate for assessing the diversity of mountain forests in Slovakia [7].

Shannon index is defined as:

$$H = -\sum_{i=1}^n x_i * \log_2 x_i \quad (1)$$

where n – number of species identified on site; x_i – ecological importance of species identified on site.

Hill index is defined as:

$$N_2 = \frac{(\sum_{i=1}^n x_i)^2}{\sum_{i=1}^n x_i^2} \quad (2)$$

where n – number of species identified on site; x_i – ecological importance of species identified on site.

Both of indices can be calculated separately for tree species, shrub species, and herb species located at the explored plots.

C. Climate Change Scenarios for Slovakia

Four general circulation models of the atmosphere (GCMs), two of which are global (Canadian CGCM3.1, German ECHAM5) and two regional (KNMI Dutch and German MPI) have been used for the analyses. All models feature the outcomes of the daily values of a number of meteorological variables from 1951 to 2100. The model outputs were selected based on a detailed analysis of 20 different models, of which 15 RCMs and GCMs 5. These models belong to the newest category of linked atmospheric-oceanic models with more than 10 atmospheric height levels and more than 20 oceanic depths calculating variables in the network nodes. CGCM3.1 model is close to Slovakia 9 nodes, a model ECHAM5 near Slovakia 12 square grid nodes (about 200x200 km) in proportion to smoothed orography. Regional models KNMI and MPI are more detailed integration of dynamic equations of atmospheric and oceanic circulation in the network nodes at a distance of 25x25 km, and boundary conditions solving equations taken from the global model outputs ECHAM5. In the area of Slovakia have models KNMI and MPI to 19x10 nodes (190) and of real orography with well defined all the mountains with a larger horizontal dimension than 25 km.

The main outputs from these scenarios are as in Table I.

TABLE I
RISE OF MEAN ANNUAL AIR TEMPERATURE ACCORDING TO THE SELECTED CLIMATE CHANGE MODELS – CENTRAL PART OF SLOVAKIA

Climate Change scenario (SRES)	2050	2075
KNMI (A1B)	+ 1.65	+ 2.62
MPI (A1B)	+1.69	+2.58
CGCM3.1 (A2)	+ 2.1	+ 3.29
CGCM3.1 (B1)	+ 1.75	+2.06

- 1) Average air temperature should be gradually increased by 2-4 °C compared with the average period from 1951 to 1980, while maintaining the same annual and inter seasonal temporal variability. A little faster should grow daily minimum as daily maximum air temperatures, causing a decrease in average daily amplitude of air temperature. The scenarios do not foresee significant changes in the annual running of air temperature in the autumn months, but would be smaller than the temperature rise in the rest of the year.
- 2) Annual precipitation should not change significantly, but rather assumes a slight increase (about 10%), mainly in the north of Slovakia. Major changes should occur in the annual running and temporal modes of precipitation. In the summer, it is widely expected slight decrease in rainfall (especially in southern Slovakia) and in the rest of the year, mild to moderate increase in rainfall (especially in winter and in northern Slovakia). In the warm part of the year it is expected to increase the variability of rainfall, probably will be extended and more frequent drought periods on the one hand and more intensive rainfalls on the other. It is expected warmer weather in the winter and up to 900 m a.s.l. snow covers the irregular and often will occur winter floods. Snow cover is likely to be higher on average only amounting to over 1200 m a.s.l., but these locations covered in Slovakia less than 5% of the area, which cannot significantly affect drainage conditions.

Detailed description of climate change scenarios for Slovakia can be found in [9].

III. RESULTS

A. Forest Gap Model – Supramontane Zone

The model simulation for current climate represents the results of biomass production in mountain forest of supramontane zone (1300 m a.s.l.). The results document the dominance of three tree species: Norway spruce, beech and fir with a small portion of maples and ash (Fig. 1). The biomass production level of the forest ecosystem has stabilized in the range of 120-140 tons of biomass per hectare, that corresponds to real mixed stands in this zone. Beech reaches 40-50 percent representation, Norway spruce 30-40% and fir 10-20%. In real stands of this area is the presence of maple and ash higher (around 10%), their occurrence is linked to specific edaphic conditions (skeleton soil, slope bases), which cannot be taken into account in the model.

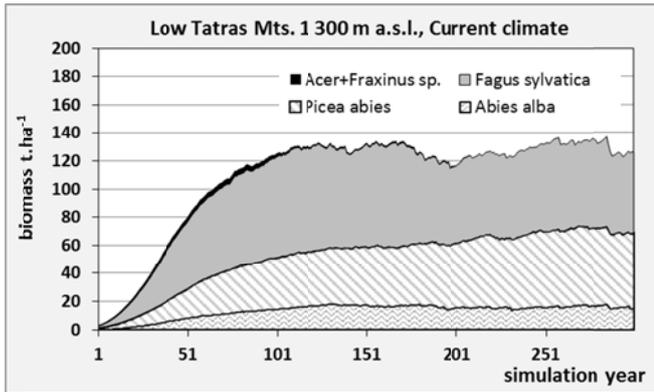


Fig. 1 The results of Forest gap model – simulation for current climate conditions (central part of Slovakia – 1 300 m a.s.l.)

A simulation model for conditions of climate change scenarios show an increase in total biomass production by about 20% (model KNMI) to 30% (model CGCM3.1 A2) (Fig. 2) compared to current climate conditions. Increased production of biomass is associated with an increase in temperature (increased soil respiration and nutrient cycling) and a longer growing (production) period, while continuing positive water balance. The tree species composition of the forest ecosystem significantly changed, where the Norway spruce completely absent. Dominated tree species in forest ecosystem have become beech, fir, maple and ash trees as tree species typical for montane zone.

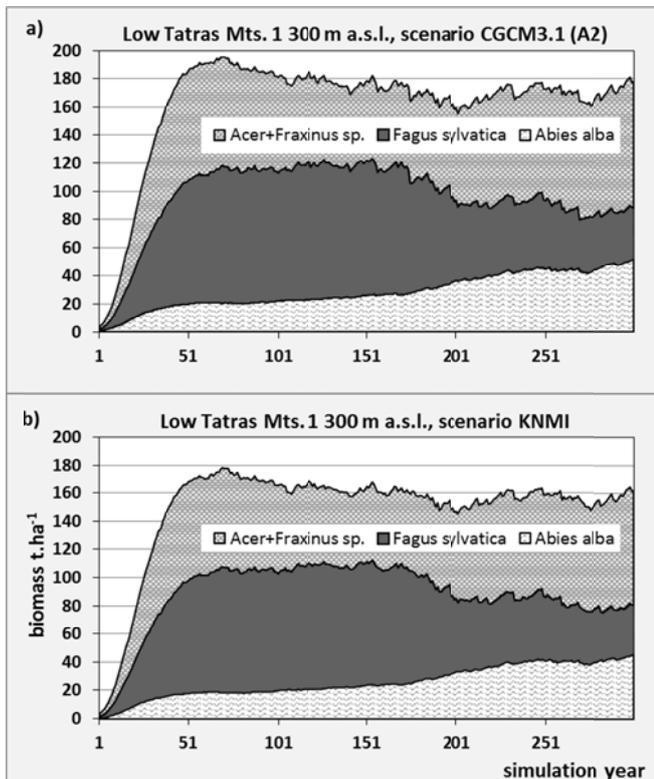


Fig. 2 The results of Forest gap model – simulation for climate change scenarios: (a) CGCM3.1 A2 and (b) KNMI (central part of Slovakia – 1,300 m a.s.l.)

B. Forest Gap Model – Subalpine Zone

The model simulation for current climate represents the results of biomass production in mountain forest of subalpine zone (1 700 m a.s.l.). The results show the situation above the current upper tree line with dominance of the shrub communities: dwarf pine (*Pinus mugo*) and scrubby forms of Norway spruce and *Sorbus aucuparia* (Fig. 3).

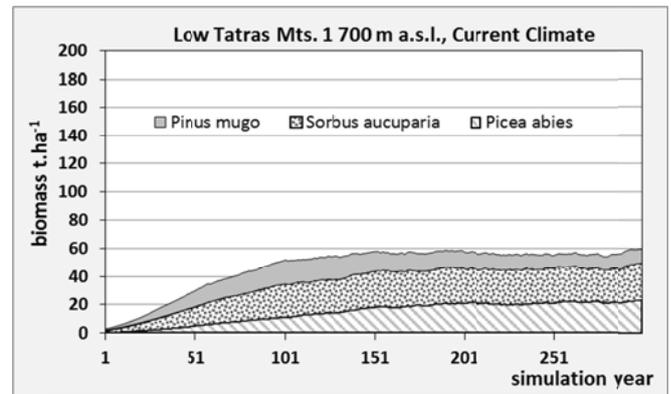


Fig. 3 The results of Forest gap model – simulation for current climate conditions (central part of Slovakia – 1 700 m a.s.l.)

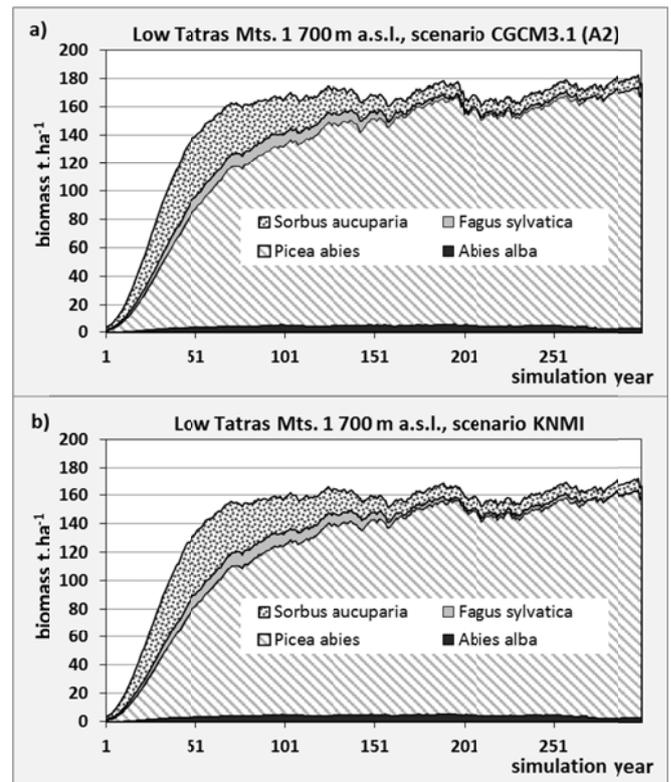


Fig. 4 The results of Forest gap model – simulation for climate change scenarios: a) CGCM3.1 A2 and b) KNMI (central part of Slovakia – 1,700 m a.s.l.)

The biomass production level of the ecosystem has stabilized in the range of 50-60 tons of biomass per hectare. This value seems to be higher than real dwarf pine communities in this region are, but most of these communities

have been destroyed by the sheep grazing during the 19th and 20th centuries.

A simulation model for conditions of climate change scenarios documents subalpine zone changed to forest ecosystems with Norway spruce as dominated tree species (Fig. 4). Increase in total biomass production is due to the onset of forest communities 2.5 times (KNMI model) up to 3 times (model CGCM3.1 A2) higher than for current climate conditions. Increased production of biomass is mainly associated with the onset of woody plants with greater production potential in a changing climate (increased air temperatures, lengthening of the growing season). Tree species composition of the ecosystem significantly changed, dominated by Norway spruce. Other tree species (*Fagus*, *Abies* and *Sorbus aucuparia*) only occur as admixed.

C. Biodiversity Indices

In the model area of the Low Tatras mountain forests were the derived regression models of climatic factors and biodiversity indices for tree species [7]. The strongest regression dependence has been detected for air temperature ($\alpha = 0.01$). The linear regression model was used for calculation of the potential changes in biodiversity indices (Shannon, Hill) in terms of climate change scenarios according to the present (Fig. 5).

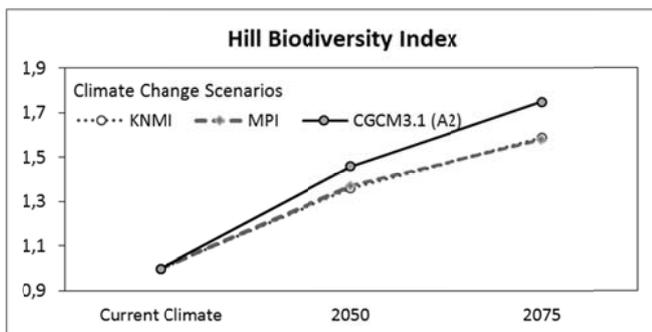


Fig. 5 Hill Biodiversity Index – changes in mountain Norway spruce forests due to climate change (central part of Slovakia – 1 300 m a.s.l.)

The results of the analysis of Hill-index changes indicates the trend of increase in the positive value of the impact of increasing the air temperature, and its value increases from a level of 0.9 to 1.9 but these values also correspond to a very low level of diversity (limit value of the index is 2.5). This is due to the small number of tree species that are occurred from the 6th up to 8th vegetation zones found in Slovakia (dominant species are *Picea abies*, *Fagus sylvatica* and *Pinus mugo*).

Shannon index has proved to be the most suitable for the analysis of diversity of mountain forests in Slovakia [7]. Therefore, we modeled the index for the current tree species composition of forests in mountainous areas as well as for the reconstructed original tree species composition (Fig. 6).

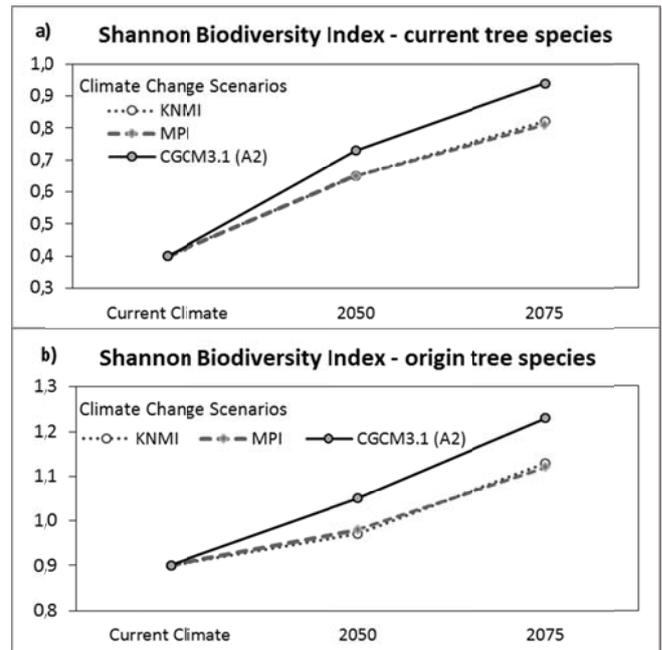


Fig. 6 Shannon Biodiversity Index – changes in mountain Norway spruce forests due to climate change (central part of Slovakia – 1300 m a.s.l.): a) Simulation for current tree species composition, b) Simulation for potential (origin) tree species composition

The current level of diversity by Shannon's index has been fluctuating around 0.4 (extremely low diversity) (Fig. 2 (a)). According to the regression model, the index value is changed due to rising air temperature and for the time horizon of 2075 reached a level near to 1.0, which is the limit for semi-low diversity level.

The conditions of the original tree species composition reflect the higher value of Shannon index. The current climate conditions, the index value ranges between 0.9 and with an increase in air temperature rises up to the value of 1.2 (semi-low diversity level) and for the horizon of 2100, the potential value of Shannon index could be reached the level of moderate diversity level (Fig. 6 (b)).

Results of the analysis of both indices show the increasing of potential diversity of tree species for the conditions of mountain forests in Slovakia under the climate change conditions. This potential can be fulfilled only for undisturbed and/or less human influenced by the development of these forests.

IV. DISCUSSION

The results point to significant changes in tree species composition of forests in mountainous areas of Slovakia. Change in tree species composition also leads to changes in biodiversity in forest ecosystems and our results suggest that climate change in mountain forests could be a driving force for increasing the level of diversity of tree and shrub components of ecosystems. This fact, however, will be largely influenced by the way of the human care or influence on forest ecosystems, which can speed up the process, but also to slow down.

Many studies in recent years have investigated the effects of climate change on the future of biodiversity. Possible effects of climate change that can operate at individual, population, species, community, ecosystem and biome scales, notably showing that species can respond to climate change challenges by shifting their climatic niche along three non-exclusive axes: time (e.g. phenology), space (e.g. range) and self (e.g. physiology). The review of the current status of knowledge shows that current estimates are very variable, depending on the method, taxonomic group, biodiversity loss metrics, spatial scales and time periods considered. Yet, the majority of models indicate alarming consequences for biodiversity [2].

Phenological observations in recent decades in Slovakia recorded a significant shift in the spring events, and this shift represents an earlier onset of each phenostages about 6-10 days [8]. The gradual warming of mountain areas will intensify this trend and the growing season will be gradually extended. A longer growing season and temperature rise can significantly stimulate the growth processes of forest ecosystems, which has been also indicated by our model calculations

It should be noted that in connection with changes in the biomass production we have to discuss about changes in carbon stocks in the mountain forest ecosystems. Increase production of above-ground biomass will certainly lead to an increase in carbon sequestration in above ground biomass. The question is how it will influence the overall carbon cycle and carbon stocks in mountain forest ecosystems. They are to be expected significant changes in soil carbon stocks, mainly due to the acceleration of soil respiration. Overall, however, cover the carbon cycle and climatic changes in ecosystems are still largely unknown [3].

The model simulated changes in the mountain forests of Slovakia can contribute to the proper setting of adaptation measures, in particular for afforestation of large calamity areas.

Potential impacts and risks related to forest ecosystems are best studied and understood with respect to wood production. It is clear that all other goods and services provided by European forests will also be impacted by climate change, but much less knowledge is available to quantify these impacts. Understanding of adaptive capacity and regional vulnerability to climate change in European forests is not well developed and still requires more focused research efforts [10].

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