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Recent Trends of Tree Growth in Relation to Climate Change in Hungary

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Abstract – The paper addresses two related issues. One is whether, and how, growth patterns of stand mean height have changed in Hungary in the last few decades, and the other is whether recently observed increases in mean annual temperature might have caused changes in growth trends. Changes in tree growth were investigated for beech (*Fagus sylvatica*), sessile oak (*Quercus petraea*) and Turkey oak (*Quercus cerris*) by comparing stand mean heights over age using data from the forest inventories of 1981 and 2001, and for sessile oak using stand mean height data from permanent sample plots since 1961. Tree growth was found to have accelerated for each species mentioned, with Turkey oak showing the largest acceleration. To study the second issue, stand mean height was related to elevation, wich in turn was related to mean annual temperature and precipitation. For these analyses, too, data of many thousands of stands in the forest inventory was used. Stand mean height was found to increase with decreasing elevation, i.e. with increasing mean annual temperature, for each of the three species. As the annual precipitation and air humidity decreases with decreasing elevation, it was concluded that increases of mean annual temperature could positively have affected tree growth in the last few decades. However, this effect is expected to be soon limited by water availability.

climate change / tree growth / beech / sessile oak / Turkey oak

Kivonat – A fanövekedés és a klímaváltozás néhány összefüggése Magyarországon. A tanulmány két, egymással összefüggő kérdést elemez. Az egyik az, hogy vajon felgyorsult-e a fák magassági növekedése az elmúlt évtizedekben, a másik pedig az, hogy e gyorsulást okozhatta-e a hőmérséklet növekedése? A fanövekedés-gyorsulást egyrészt az Országos Erdőállomány Adattár 1981-es, illetve 2001-es erdőrészlet-adataiból bükkre, kocsánytalan tölgyre és cserre levezetett kor-magasság görbék összehasonlításával vizsgáltuk, másrészt pedig hosszúlejáratú fatermési kísérleti területek adatainak trendelemzésével kocsánytalan tölgyre. Mindegyik esetben a növekedés gyorsulása volt kimutatható; leginkább a cser növekedése gyorsult fel. E gyorsulás okainak vizsgálatához összefüggést kerestünk az Országos Erdőállomány Adattár található sokezer erdőrészlet tengerszint feletti magassága és a fák átlagmagassága között. Kimutattuk, hogy az átlagmagasság – minden egyéb tényezőt állandónak tekintve – nőtt a tengerszint feletti magasság csökkenésével, ami megfelel az átlaghőmérséklet növekedésének. Mivel a csapadék éves mennyisége csökken a tengerszint feletti magasság csökkenésével, ezért azt a következtetést vontuk le, hogy az elmúlt évtizedek magasabb hőmérséklete valóban intenzívebb növekedéssel párosult. A jövőben a hőmérséklet-növekedés hatását azonban várhatóan korlátozni fogja a rendelkezésre álló víz abszolút vagy relatív csökkenése.

klímaváltozás / növekedésgyorsulás / bükk / kocsánytalan tölgy / cser

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1 INTRODUCTION

In its most recent assessment report, IPCC (2007) suggested that a „global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems”. Based on data, models and scientific reasoning, the report also stressed that, „globally, commercial timber productivity rises modestly with climate change in the short- to medium-term with large regional variability around the global trend”.

For Europe, Nabuurs et al. (2002) suggested, based on model simulation, that increment could grow by 18% by 2030, and slow down on a longer term. Solberg et al. (2003) suggested increased wood production in Western Europe, but a decreased production in Eastern Europe. Finally, Schroeter (2004) also suggested increased forest growth in most parts of Europe, especially in Northern Europe.

With respect to tree growth, these findings could sometimes be expected as a consequence of the recent warming in Europe. However, without evidence that is based on measured data it is not entirely clear how and to what extent tree growth may change due to climate change.

Since tree growth is not only a biological process, but also affects the economic, social and environmental aspects of forestry, and since it can be measured relatively cheaply and accurately (as compared to most characteristics of ecosystems, such as food chain), one of the first consequences of climate change to study in Hungary was tree growth (Mátyás 1994, Somogyi 1998.a-c, Somogyi 2001, Makkonen-Spiecker-Somogyi 2000).

Another reason of the interest in tree growth is that its patterns seemed to have changed throughout Europe over a decade ago, and studies were conducted, even without considering climate change, that were widely publicized. Kuusela (1994) was among the firsts to show, by analysing the forestry statistics of the European countries, that the standing volume and current increment had considerably increased during the previous 40 years, although the amount of harvest had also increased. This study was followed by that of Spiecker et al. (1996) who, in addition to studying the issue whether tree growth could have increased or not, also attempted to address why it could have happened. The studies included analyses of forest inventory data, but also data from scientific studies such as permanent sample plots and tree ring analyses where accuracy is of high importance. The synthesis of the results suggested a more or less accelerated tree growth rate in most parts of Europe.

In Hungary, tree growth was not suspected to have changed in the 1980’s (Király 1986), however, several case studies applied the hypothesis that it might have changed (Somogyi 1998a-c, Makkonen-Spiecker-Somogyi 2000, Tóth 1998, Szabados 2007). The results suggested that a large-scale study was necessary.

In this paper, which reports on the results of this study, two main questions are focused on:

I. Is there any indication of a recent change in the growth pattern at the country level?

II. Could the recent climate change result in changes in tree growth?

These questions cannot directly be answered, therefore, operative questions, two for each questions above, were formulated, also considering all available data. These are the following:

I(a) What was the growth trend like of three important tree species, i.e. beech, sessile oak and Turkey oak between 1981-2001 using forest inventory data of the National Forestry Database (NFD)?

I(b) What was the growth trend of sessile oak like in permanent sample plots?

II(a) Could any relationships be found between tree growth rate and site characteristics that are strongly affected by mean annual temperature?

II(b) In case there are such relationships, could the increase of temperature between 1981-2001 be shown to bring about the observed tree growth change (under I above) during the same period?

2 METHODS AND DATA

The above questions required different methods, assumptions and data, therefore, they are detailed in relation to the questions themselves. The same applies later for the results.

I. Recent tree growth trends

Of all possible measures, tree height was analysed to detect trends as it was available in each dataset, and it strongly correlates with site. The heights or height growths of the same species were compared in different years or time periods with the assumption that, within the limits of sample errors and the errors of the measurements, the same site brings about the same height growth. It is the same to say that, if site has changed, it affected height growth.

Another main element of our approach was that all anayses were done using all data available in the country, i.e., using the largest sample size, by which the effects of local differences of site, forest management etc. of the samples, that could have affected the results, could be minimized.

Question number I(a) was analysed using stand data from the NFD for sessile oak (*Quercus petraea* Liebl., SO), common beech (Fagus sylvatica L., CB), and Turkey oak (*Quercus cerris* L., TO). Only those stands were included where the water available for the roots only included water from precipitation (i.e., stands under the influence of floods were excluded). For all these stands and for all species in the stands, and for both 1981 and 2001, age, species ratio (by crown projection), origin (seed, coppice), mean stand height, mean stand diameter, standing volume, as well as site characteristics (see below) were queried from the NFD. From the mean stand height and age data, age-height curves were developed for both 1981 and 2001, and these curves were compared using regression and correlation techniques.

Question number I(b) was analysed using data from the SO permanent sample plots of the Hungarian Forest Research Institute. Here, too, the mean stand height data were plotted against age. In this analysis, different number of data per sample plot could be used depending on when observations started on the sample plot (the difference of the age of the stand between two consecutive measurements of the same sample plots is usually between 5-10 years). The sample plots included silvicultural experiments where a range of thinning intensities was experimented with. Including all plots of the experiments, often with different stand densities, was based on the assumption that, within wide ranges, thinning does not affect mean stand height. Intensive thinnings, which might have increased mean stand height causing mean stand height to tend lower, only occurred during the 1960'-1970's, and stands became much denser later. Thus, including these experiments could not result in the increase of the observed mean stand height growth, rather, it could only reduce any observed increase of height growth.

II. Site - tree height and site change – tree growth relationships

When studying the effects of climate change, two important climatic factors to analyse are temperature and precipitation. Unfortunately, these data were not directly available as they are not measured and stored in forestry databases, and were not available at an appropriate density from other (e.g. meteorology) databases, either. On the other hand, we suspected that relationships may exist across large areas, i.e. at the average of many stands, between these climatic factors and two measures that are assessed for each stand in Hungary: elevation and forest climate type. Elevation (EL) is measured, and stored in the NFD, for each stand at the nearest hundred m. Concerning forest climate types (FCT), four types are used in standard site assessment based on the occurrence of main tree species which is thought to correlate well with the joint effects of all climatic factors. These four types, named after the main indicator tree species themselves, are Common Beech Type (CBT), Hornbeam-Sessile oak Type (HST), Turkey Oak Type (TOT), and Forest Steppe Type (FST). According to Mátyás-Czimber (2000), the difference between the mean July monthly temperature of CBT and HST is 0.9 degrees ºC, whereas that of HST and TOT is 0.2 ºC, and the difference between the mean annual precipitation of CBT and HST is 32 mm, whereas that of HST and TOT is 86 mm.

In the present study, multiple regression techniques were used to detect relationships between mean stand height on one hand, and EL and FCT on the other, to address question number II(a). The regression analyses were made by FCT so that, within each FCT, further categories were created using other standard site parameters available in the NFD: aspect, soil type, rooting depth, as well as physical soil characteristics. However, due to limited data availability, only those categories were considered where tree growth was limited by the amount of precipitation, and where a number of stands was available that could allow to perform statistical tests. Of all possible combinations of the above site characteristics, 84 site categories were studied. Based on the relationships found, simple relationships between temperature and tree growth were developed, using a simple meta-analysis of the results by all site categories, for the three tree species of question number I.

Finally, in analysing question number II(b), the relationships found under II(a) were used to estimate how much increase of tree growth could be attributed to the observed increase of mean annual temperature between 1981-2001. Using the above relationships, predictions were also made in several scenarios of possible future increase of temperature.

3. RESULTS

I. Recent growth trends

I(a) Several thousands of mean stand height data were available for all three tree species from the NFD (not shown in the figures below). The second order polinomial age-height curves fitted for these data for 1981 and 2001, which should overlap, show significant differences for a range of age classes (*Figure 1*).

A more detailed analysis of differences by age classes, as well as FCT and origin (*Table 1*) shows more detailed tests of significance. The more categories we have, the less is of course the number of stands in a category, therefore, the less is the chance to find significant differences, and indeed, less significant differences were found, and non significant catagories were found, too. There are also categories where the mean height is lower in 2001 than in 1981. However, overall, the 2001 mean heights were generally larger than the 1981 mean heights in the same species, site and origin categories (*Table 1*). In the latter, „main” means stands where the given species is a main species, i.e. its species ratio is more than 50%, whereas „mixed” means stands where the species ratio is less than 50%. Dark cells indicate significantly higher mean heights of the same age (in 2001), light gray colors indicate non-significantly higher mean stand heights, whereas middle gray colors indicate non-significant lower mean heights. There were no significant lower mean stand heights in 2001 than in 1981. White cells indicate classes with not enough number of stands in the respective category.

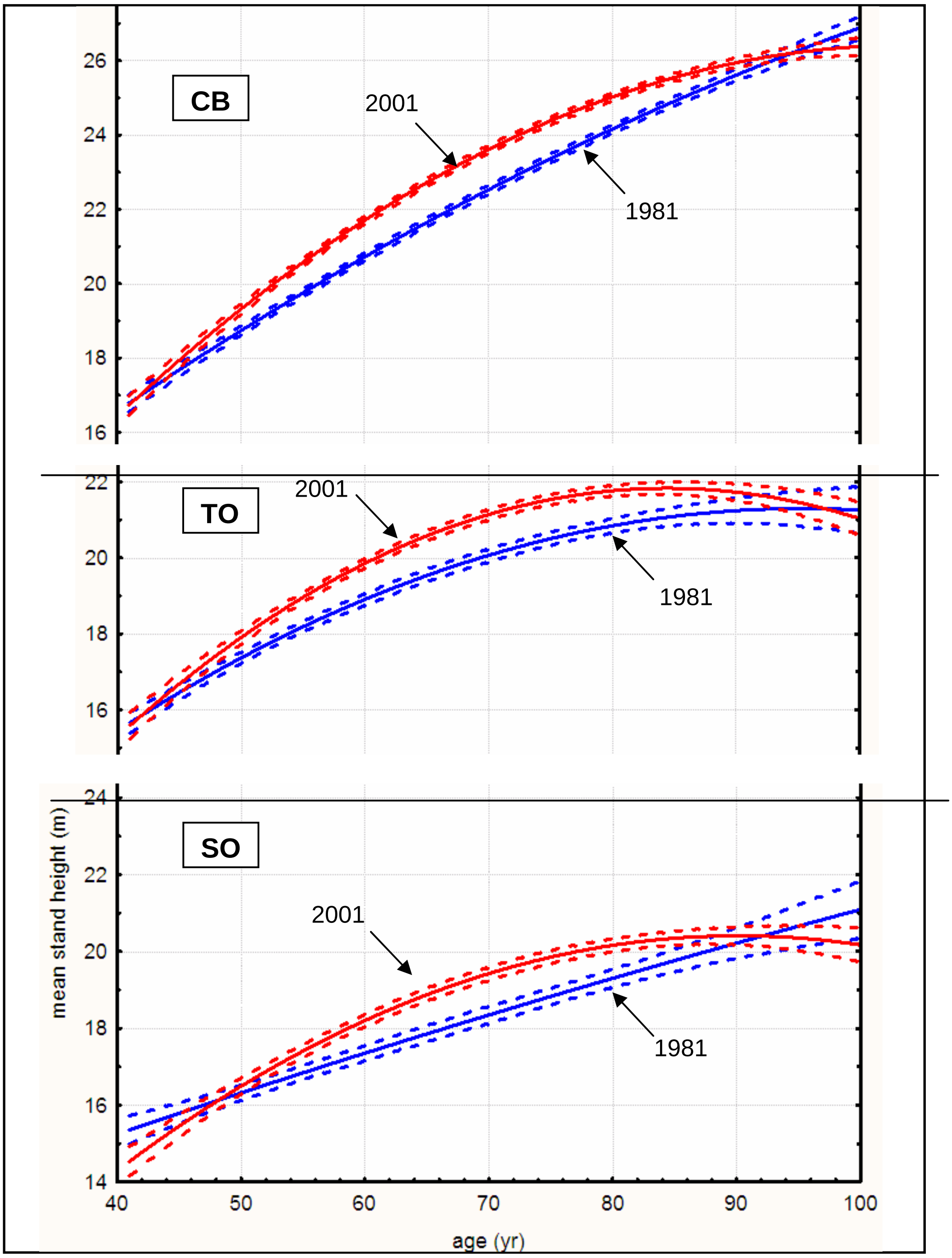

Figure 1. Second-order polinomial age–mean stand height curves, based on data (not shown in the figure) from the NFD, for species SO, TO and CB for 1981 (continuous line) and 2001 (continuous line), together with the confidence bands of 95% probability (dashed lines).

Table 1. The difference between the mean stand heights in 2001 and 1981 by age class for SO, TO and CB species by the origin (seed or coppice) and species ratio categories.

Origin	Mixing	Age class (year) 41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120
					SO				
seed	main			2,57	0,50		-0,42	0,83	0,23
	mixed	0,37	-0,24	-0,78	-0,36	0,26	0,23	0,06	0,04
coppice	main		3,38	0,98	2,66	2,27	1,59	1,35	1,33
	mixed		2,04	0,02	1,98	1,27	1,68	0,23	3,30
					CB				
seed	main			1,23	0,25	4,71	1,28	0,65	0,00
	mixed		0,10	3,03	1,21	2,30	0,09	1,19	2,35
coppice	main					5,70	3,80	1,11	2,75
	mixed			0,25	2,46	2,35	2,45	0,59	5,27
					TO				
seed	main			-0,99	0,10	1,04	0,59	1,49	3,38
	mixed		0,16	0,52	0,09	1,24	0,53	1,03	1,32
coppice	main		1,64	0,40	1,12	2,09	3,49	3,03	6,21
	mixed		2,53	-0,28	2,45	1,83	2,43	1,76	2,17

I(b) Data from SO permanent sample plots were grouped so that one group contained measurements that were taken before 1990, and the other group contained measurements that were taken after 1990. A second-order polinomial curve was fitted to both datasets (*Figure 2*).

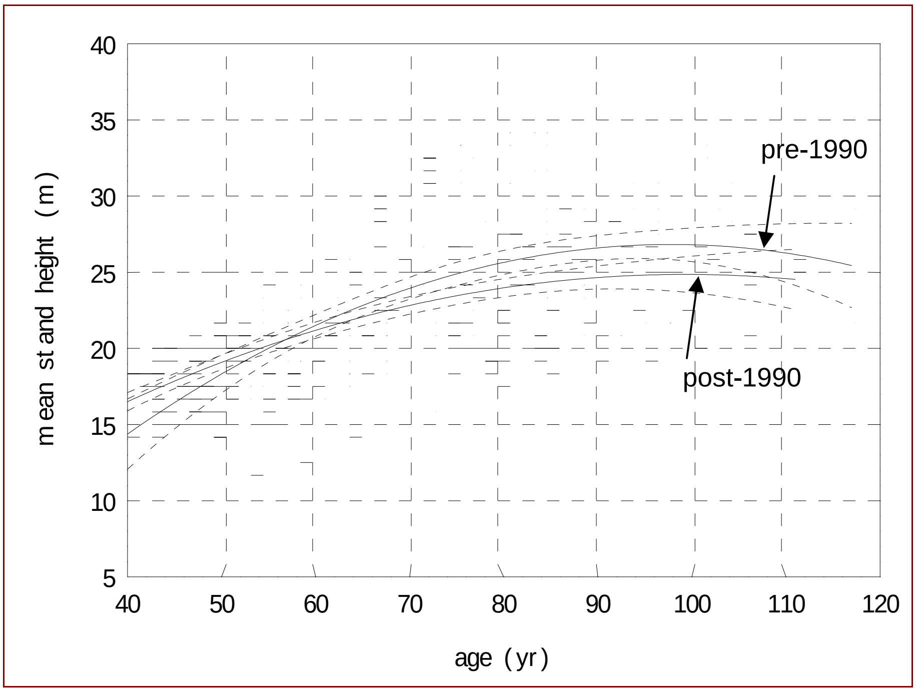

Figure 2. Second order polinomial fits to mean stand height data of SO permanent sample plots for pre-1990 measurements (thick continuous line) and post-1990 ones (thin continuous line), together with confidence bands of 95% probability (dashed lines).

In general, the curve fitted to the post-1990 measurements goes higher than the one fitted to the pre-1990 measurements. Significant differences were found between ages 75-95 years.

II. Site-tree growth relationships

II(a) The relationships between elevation and mean stand height was modeled using linear regression models with the data from the NFD. The basic assumption was that *ceteris paribus*, i.e. everything else (species, FCT, soil type, aspect) being the same, mean stand height is determined by the elevation. The linear model was developed for all possible species and site combinations between 300-600 m a.s.l where we had enough data. The regression coefficients (i.e. the coefficients of the slope of the linear line) varied between -1.6 and 0.8 and represented a normal distribution (*Figure 3*). The full confidence interval of 95% probability is found in the negative range for each tree species, and the mean value of the regression coefficients is a negative number, i.e. -0.499 for CB, -0.57 for TO and -0.29 for SO. It thus seems that generally, although with a high deviation, elevation has a discernible effect on mean stand height, and mean stand height decreases with the decrease of the elevation.

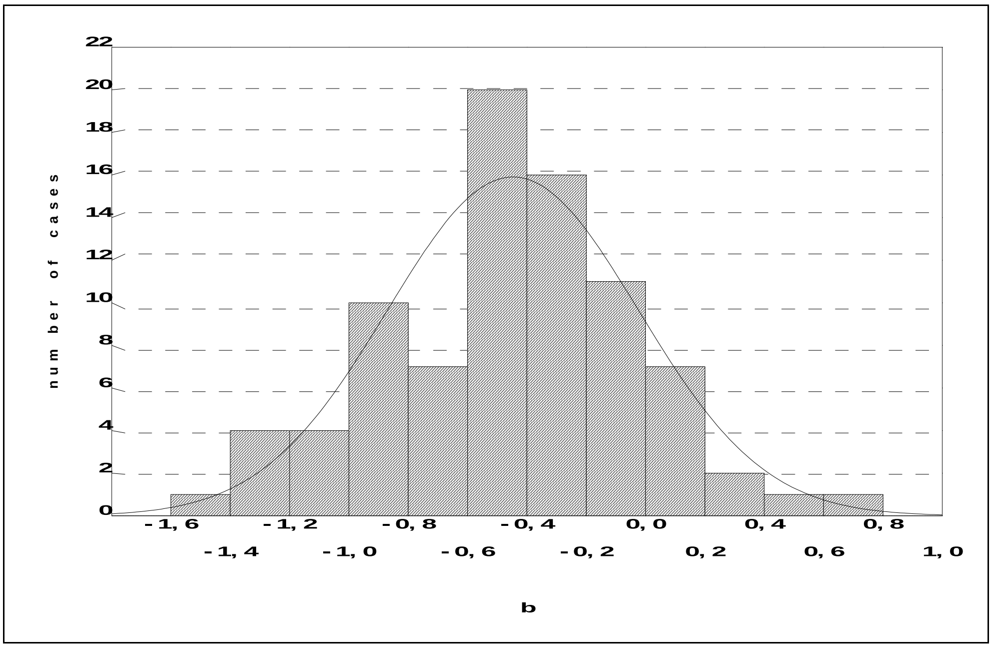

*Figure 3. The distribution of the regression coefficients (b) of the linear model: mean stand height = a + b * elevation for all species taken together and for all possible site categories, for elevations between 300-600 m (N = 84; mean value = -0.454, and the confidence band is found between -0.545 and -0.362). Similar distributions were found, with different mean values, by species (see text).*

Relationships between FCT and mean stand height was also modeled by species, as well as main soil types, using second-order age-height polinomial curves. *Figure 4* demonstrates that, for SO and on typical brown forest soil types, significant differences exist between the age-height curves of the different FCTs. The differences by FCT are more expressed than those by the elevation. However, standard deviation is usually high, and, although differences are often found, the number of stands by a site class is usually not enough to find significant differences. Generally, trees grow highest in the CBT, they grow lower in the HOT, and lowest in the TOT (there are very few occurrences of the three species studied in the FOS forest climate type).

We note here that it may seem paradoxical that mean stand height decreases with the decrease of the elevation, but it increases with the FCT when moving from TOT towards CBT (CBT is usually found at higher elevation than TOT). However, elevation is only one factor that determines FCT, thus, moving along elevation and FCT is not equivalent to moving along the same axis but in opposite directions, rather, elevation and FCT are different dimensions of the same niche. In any event, we do not have a coherent theory on how FCT affects tree growth, and further studies are needed to identify the effects of the various factors in relation to FCT that may affect tree growth.

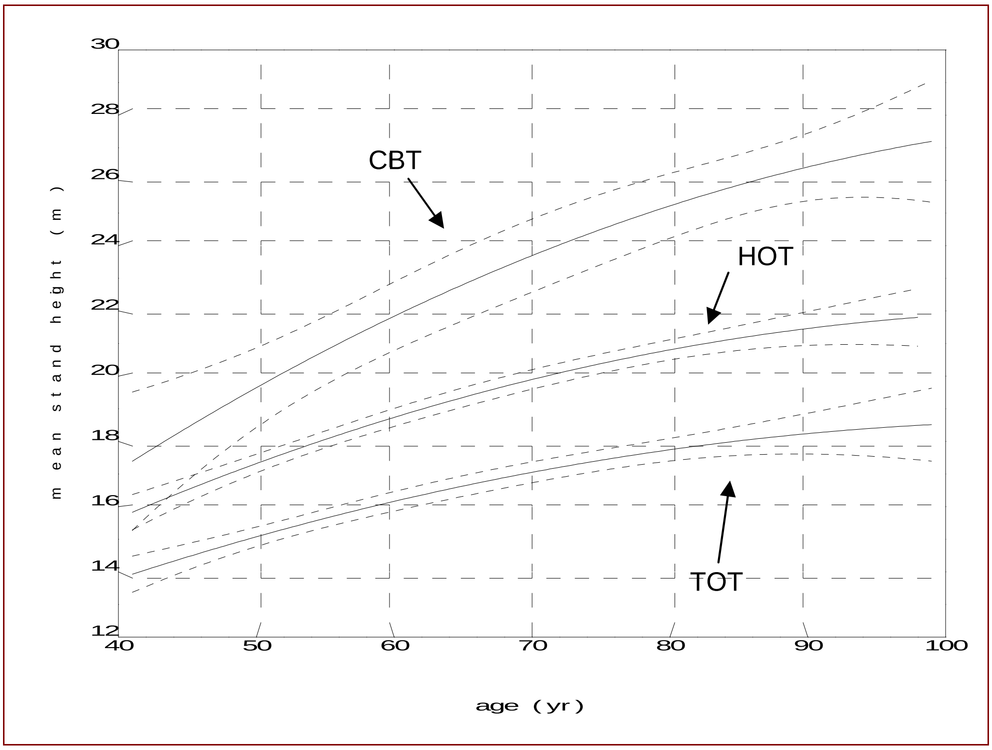

Figure 4. Age-height curves (continuous lines) by FCT for SO stands on typical brown forest soils and in Southern aspects. Dashed lines represent confidence bands of 95% probability. The upper lines are fitted to data of stands in CBT (the data are not shown in the figure), the lines in the middle are for HOT, and the lower lines are for TOT.

II(b) We have estimated what increase of height growth could occur, by applying the relationships of the II(a) analysis, assuming an increase of temperature of 1.0 ºC that was observed in Hungary between 1981 and 2001. We also estimated what would happen in the future in case of a further temperature increase of 0.5 and 2.0 ºC. (Note that these increases are the same or higher than the differences between the mean annual temperatures of the various forest climate types that were mentioned above, see Mátyás-Czimber 2000.)

As a first step, it is necessary to define growth increase potential. It is

- a long-term average increase of the tree height growth
- if mean annual temperature increased in the long term by X ºC (i.e., if the mean temperature stabilized after an X ºC increase),
- and if all other factors that influence tree growth remained the same, including e.g. the amount of precipitation.[1]

[1] According to our current knowledge about the precipitation, it will decrease somewhat in Hungary. However, even with the same amount of annual precipitation, it can occur that the precipitation becomes a growth limiting factor according to Liebig's law of the minimum. This, however, does not have any major effect on the conclusions of our study

In the second step, we must convert elevation to temperature. In Hungary, the mean annual temperature changes by 0.5-0.6 ºC by every 100 m change of elevation, and this change can be assumed linear. In the third step, if the linear model under II(a) above is applied to the mentioned temperature changes than we get an average potential tree height growth increase of 0.45 m for every 100 m increase of the elevation. Formulated in yet another way, every 0.1 ºC increase of mean temperature (across all age and site classes and for all tree species studied) is equivalent to a height growth increase of 0.07 m. The species specific values are the following: CB, 0.1 m/0.1 ºC, SO, 0.05 m/0.1 ºC, and TO, 0.1 m/0.1 ºC. Finally, using these values and assuming three scenarios of temperature increase, the potential tree height growth increase values can be calculated for all tree species (*Table 2*).

Table 2. Tree growth increase potentials (for its definition see text above) in three scenarios of temperature increase by tree species, calculated from the linear model under II(a) and all assumptions and calculations under II(b) above.

Tree species	Mean increase of tree height (m) if the increase of mean temperature is (ºK)		
	0.5	1	2
Common beech (CB)	0.5	1	2
Sessile oak (SO)	0.25	0.5	1
Turkey oak (TO)	0.5	1	2

4. DISCUSSION

The results of the study of recent growth trends (questions number Ia and b) suggest that tree growth has recently increased in Hungary. The study involved many data (and all data available) that eliminated the errors of individual tree height measurements. We also checked whether there were any changes in the methodology of mean stand and individual tree height measurements during the forest inventories between 1981 and 2001, however, according to information that we received from the National Forest Service, which runs the forest inventories, there were no such changes. Thus, we concluded that there is high confidence that tree height growth has indeed increased.

Concerning site-growth relationships (question number IIa) it must be stressed that both temperature and precipitation are very complex factors, and neither any mean value (annual, monthly, or for the „vegetation season"), nor totals, minimum or maximum values (again for a year, a month or for the vegetation season) are enough to fully predict tree growth, even if any of these factors are Liebig-minimum values at least for a certain period of time. The application of the elevation, a data that is available in the NFD, as a temperature-proxy has the advantage that no such means, totals, minima or maxima were used but a complex, although proxy, variable that integrates all of these, both for temperature, as well as for precipitation.

With the decrease of elevation, the mean annual temperature increases and the amount of precipitation decreases, which means that using the elevation as a proxy will only show the effect of temperature in the increase of tree growth, and the decrease of the precipitation may only result in an underestimation of this tree growth increase (i.e., we get a conservative estimate for the temperature – tree growth increase relationship). It is, however, clear that we only identified statistical (correlational) relationships between temperature increase and tree growth increase, and not causal relationships.

We applied the *ceteris paribus* principle for each other tree growth limiting factor that were available in the NFD. This means e.g. that, when studying the possible effects of the elevation, we only involved data of those stands that had the same other characteristics, such as tree species, FCT and soil type. Again, many other factors that could not be included in the analysis, such as the amount of photosintetically active radiation and the like, do cause tree growth to change in directions opposite to temperature (e.g., they decrease tree growth when temperature increases), thus, ignoring them only leads to an underestimation, or conservative estimation, of the possible effects of warming.

As mentioned before, tree growth was modeled using tree height which is age dependent. The effects of age on the regression coefficients in *Figure 3* could sometimes be shown, however, it could not be shown in other cases. This does not mean that the elevation, or the related mean annual temperature, do not affect growth, it only means that, in addition to the elevation, age, aspect etc., there may be other factors that affect growth, or we did not have enough data in certain species-site categories.

Concerning the effects of the elevation and the FCT, the latter showed stronger correlation to growth than the elevation. This may be explained by the fact that the FCT is a more complex indicator of all factors affecting growth than the elevation. But because FCT is not only defined by the temperature, and because no direct relationship is known between FCT and temperature, we could not use it to predict the increase of tree growth in relation to the change of temperature. On the other hand, FCT is defined by the very occurrence of the species themselves, however, the occurrence of a species does not only depend on the requirements of these species to the physical environment, but also on the competition of these and other species with overlapping niche elements, therefore, it can occur that a characteristic species of a FCT grows better in another FCT (e.g. SO in the CBT, *Figure 4*).

In any event, further analyses will be required, using geographical information systems, to better understand the relationships between the elevation and tree height growth. Many site type combinations could be defined using the site characteristics that are available in the NFD. We did not analyse all these combinations, but not only because many of these characteristics may not have strong relationships with tree growth, but because our intention was to establish relationships at the country level. These relationships are most probably not linear, and depend on age and many other factors that could not be involved in the analyses.

When studying the possible effects of the temperature on tree growth in various scenarios (question number II(b)), the estimated increase of tree growth corresponds well with the observed changes between 1981-2001, thus, we concluded that the observed increase of temperature in the country recently could give rise to the observed changes in the tree growth. We, however, again stress that we only studied statistical correlations, not causal effects.

Finally, we note that the rate of increase of volume growth that may be a resultant of the increase of tree height growth will probably not justify a substantial increase of the annual allowable cut. Also, as a consequence of Liebig's law of the minimum, a further increase of tree growth due to a further increase of temperature may not happen at all (Mátyás–Nagy 2005, Mátyás, 2006). According to IPCC (2007), globally, the wood production could only be increased slightly in the short- and medium-term up to a further 1-3 ºC temperature increase. This is because the trees' requirements to water will increase at a speed that is higher than the speed of the temperature increase, and, according to the current predictions, the amount of summer precipitation is likely to decrease, and is going to limit tree growth accross large areas as the amount of precipitation is already close to the limiting amount. It can be assumed that both trees, as well as forest management may only have a few more years, possibly a few decades, to successfully adjust and adapt to the effects of climate change.

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