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Changes of Frost Damage and Treeline Advance for Swiss Stone Pine in the Calimani Mts. (Eastern Carpathians, Romania)

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Abstract — Checking the tree-ring structure of 39 living and 9 crossdated dead samples of Swiss stone pine (*Pinus cembra* L.) collected from the upper timberline of the CalimaniMts. we have identified 59 frost rings over the past 250 years. We found concentrated occurrence of frost events in three decades: in the 1790s, 1810s and 1910s. No frost ring was observed in two bidecadal periods: 1750-1770 and 1850-1870. Out of the analysed interval 1963-2004 is the longest period without frost ring occurrence. After 1920 both frequency and severity of frost events seem to decrease compared to the prior 170 years. We determined the altitude of highest growing stone pine individuals in the Bradului Ciont–Pietrosu region in June, 2006. Individuals were sorted into tree-form or bush-like morphological groups. Mean elevation data of the groups were corrected by an estimated constant bias of GPS measurements (-30 m). Comparing the corrected values to early 20th century inventory data 65 m and 95 m upward migration was determined for treeline and boundary of bush-like occurence, respectively. The parallel results suggest that the 20th century advance of the upper forest limit was due to the decrease of frost stress at the zone of timberline.

Swiss stone pine (*Pinus cembra* L.) / late frost / timberline / frost ring / climate change

Kivonat – Cirbolyafenyők fagykárosodása és az erdőhatár változásai a Kelemen-havasokban (Keleti-Kárpátok, Románia). A Kelemen-havasok felső erdőhatárán növekvő cirbolyafenyők évgyűrűszerkezetének vizsgálata során 59 fagygyűrűt ismertünk fel. Az 1750-2004 időszakban a mintaszám elég magas, a vizsgált egyedek átlagos életkora elég stabil ahhoz, hogy a fagygyűrű észlelések előfordulási gyakoriságai alapján kijelentsük:

1) 1790-es, 1810-es és az 1910-es évtizedekben koncentráltan fordultak elő fagyesemények.
2) 1750-1770, 1850-1870 és 1963-2004 intervallumokban nem találtunk fagygyűrűt.
3) 1876-ban érintette az állományt a legdrasztikusabb fagyesemény 1750 óta.
4) 1920 után a kései fagyok erőssége és előfordulási gyakorisága is csökkenni látszik a megelőző 170 évhez képest. Ezt nem magyarázhatjuk a vizsgált egyedek átlagos életkorának emelkedésével, mert az életkor szórása is növekszik, jelezve, hogy az idős – fagytűrőbb - egyedek mellett fiatal - fagyérzékeny - példányok is vannak.

GPS segítségével 2006 júniusában meghatároztuk a legmagasabban növekvő cirbolya példányok tengerszint feletti magasságát. A bemért példányokat alak szerint két csoportba (fa alakú, bokor-szerű) soroltuk. A mért magasságokat kontrol mérések alapján korrigáltuk. A korrigált magassági adatokat a

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XX. század első évtizedében készített részletes felmérés adataihoz hasonlítottuk. A 2006-os fahatárra 65, az eltörpült, bokor-szerű példányokra 95 méterrel magasabb értéket kaptunk, mint amit száz évvel korábban közöltek.
Az eredemények azt sugallják, hogy a felső erdőhatár XX. sz-i előrenyomulása a fagy-stressz mérséklődésének tulajdonítható, melyet a fagyesemények intenzitásának csökkenése igazol.

Cirbolyafenyő (*Pinus cembra*) / kései fagy / erdőhatár / fahatár / klímaváltozás

1 INTRODUCTION

High mountain zonation is a prominent indicator in climate change investigations (Gottfried et al. 1994, Pauli et al. 2003). The clearest, visible boundary in mountain vegetation is the transitional belt between forest and alpine meadows. Within a mature, natural forest/meadow transition zone three further boundaries should be mentioned (Körner 1998). The upper limit of closed forest is the timberline. The discontinuous line following the altitudinal boundary of tree-form individuals is the treeline, while the uppermost virtual line above treeline where only seedlings and dwarfed individuals appear is the tree species line. The same belts are present in the taiga/tundra transition zone too.

Owing to its pronounced climatic determination this transitional zone is in the highlight of tree-ring research (Fritts 1976).

Temporal fluctuations in treeline position have been described at many sites (Luckmann – Kavanagh 1998, Esper – Schweingruber 2004, Koch et al. 2004, Nicolussi et al. 2005, Mátyás 2006).

Our investigations aim to detect the climate sensitivity of stone pine in Calimani Mts. and to evaluate its potential to reconstruct environmental history. The relationship of climate and ringwidth fluctuation is assessed in separate papers both on interannual (Kern et al. 2007) and decadal/centennial scale (Popa – Kern accepted). This paper analyses the frequency of anatomical deformations of wood related to temperature drops during the vegetation period between 1750 and 2004. In addition we present the first results from the Carpathians confirming the upward advance of upper treeline since the first decade of the 20th century.

2 MATERIAL AND METHODS

2.1 Site description

The Calimani Mts. is the highest volcanic range in the Carpathians. The central part is characterized by a northward opened caldera. Steep slopes ascend from the inner depression to the rim of the caldera, while gentle slopes descend towards the pediment. The highest peaks are mounds on the rim. The range culminates at the Pietrosu peak (2102 m asl) (*Figure 1*).

The elevated terrain at the central range hosts coniferous forest. subalpine vegetation zone grows above the timberline while patches of stony tundra with blanket of lichens can be found in the regions of the highest peaks (Nagy et al. 2006). Natural timberline (~1700 m asl) is well preserved at the steep north facing slopes where anthropogenic influence (e.g.: grazing, wood cutting) was negligible. Timberline is characterized by Norway spruce (*Picea abies* (L.) Karst) and Swiss stone pine (*Pinus cembra* L.). The local pine occurrence represents the eastern boundary of European distribution area of the species. Stone pine individuals also appear on the southern side descending toward the Mures Valley, but the largest stands are are located on the northern slopes of Rachitis Peak and Pietricele Peak (Höhn 2001). The southern side population has lower genetic variability compared to northern side one (Höhn et al. 2005).

Recent dendroecological investigations proved that temperature exerts significant positive influence on annual growth of the stone pine at the Eastern Carpathian timberline (Popa 2005, Kern et al. 2007).

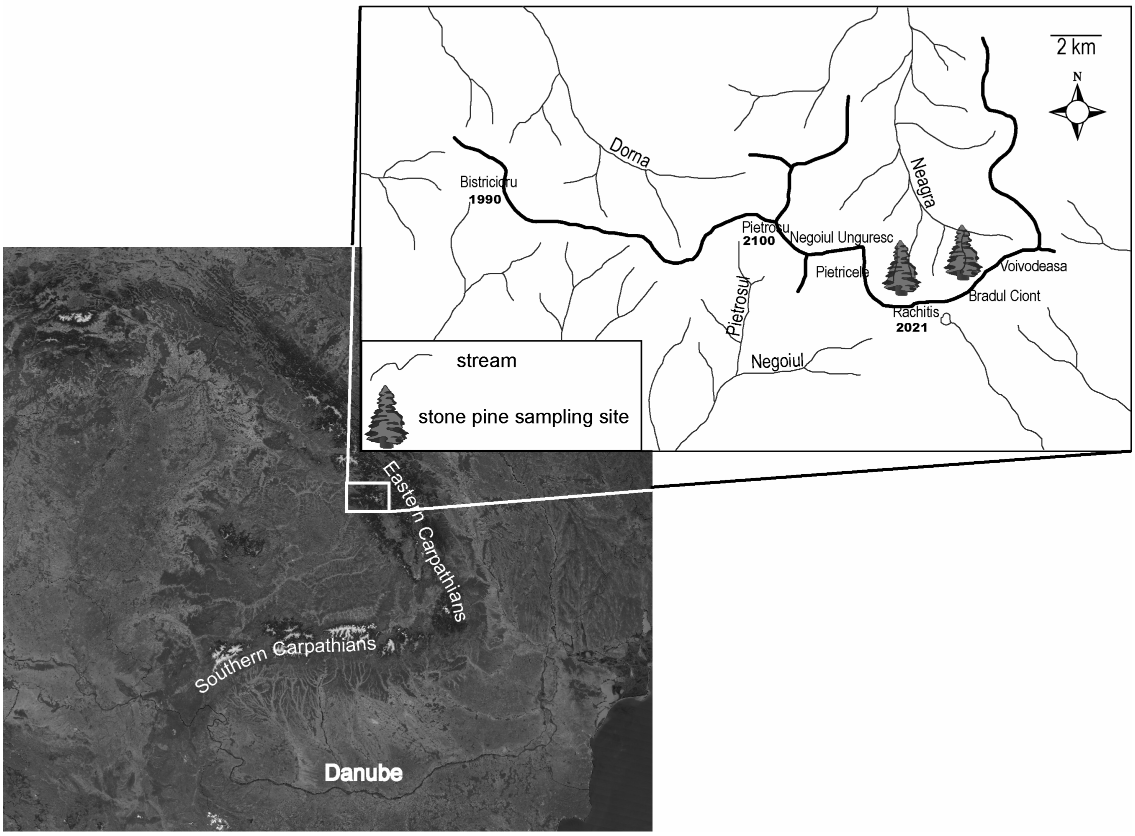

Figure 1. Location of the Calimani Mts in the Eastern Carpathians. The sketch map shows the study site within the area (MODIS image downloaded from: http://visibleearth.nasa.gov)

2.2 Sample collection and preparation

The research area is the upper timberline below the Rachitis Peak and Bradului Ciont Peak (*Figure 1*). We have collected samples from living trees and numerous dead trees lying on the ground between 2003 and 2006. Samples' surfaces were prepared by abrasive belt and polished, so the tree-ring boundaries became distinguishable under binocular microscope.

Beside classical dendroclimatological investigations occurrences of frost rings (*Figure 2)* were also recorded. Checking the tree-ring structure of 39 living and 9 reliably crossdated dead stone pine samples collected from the upper timberline of Calimani Mts. we have identified numerous frost rings (*Figure 2*).

Two characteristics were recorded for each identified frost ring:

- Calendar date of the tree ring displaying the frost ring.
- Cambial age of the tree when the frost ring has developed.

Cambial age was precisely determined by ring counting when boring hit the pith. If an extracted increment core or a hollow disk lacked the pith then the missing rings (pith-offset) were estimated by pith locator (graphics of concentric circles).

Number of trees and frost ring frequency were determined for each year. Frost ring frequency was calculated in a given year as number of frost damaged tree rings divided by the total number of tree rings. In addition, mean age and corresponding standard deviation were also calculated year-by-year from the sample set.

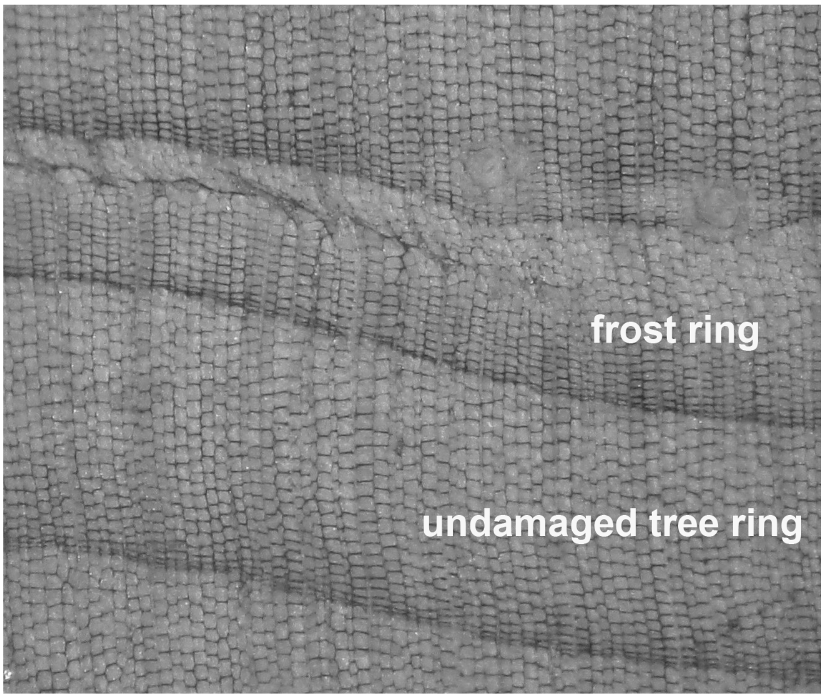

Figure 2. Undamaged vs. frost-affected tree rings as seen on a polished surface in radial transect. The characteristic deformation (frost ring) in the narrower ring is caused by collapse of cells. Note that frost ring does not necessarily extend around the entire circumference!

2.3 Altimetry

We determined the altitude of occurrence of the highest growing stone pine individuals along the Bradului Ciont–Pietrosu part of the caldera-rim in June 2006. We applied Mobile Mapper GPS reciever in mapping.

Specimens were sorted into tree-form or bush-like morphological groups in order to ease comparison between actual and early 20th century inventory data (Fekete – Blattny 1913).

Our original plan for the correction of GPS-measured elevation data by phase measurement failed due to technical difficulties. We had to apply a rather simple method to estimate the difference between the GPS-derived elevation, above ellipsoid, and the real elevation above sea level. The altitude of the Rachitis meteorological station (~2020 m asl) was measured in the mornings and in the afternoons of the work-days of mapping. The resulted elevation data scattered in the 2047.7-2052.5 m range suggesting a roughly constant, 30 m overestimation for the GPS derived elevation data. To improve precision we reduced all elevation data by 30 m in the final comparison (see *Tables 1* and *3*).

3 RESULTS

3.1 Frost rings

The final chronology covers the 1664-2004 period. We have identified in total 59 frost rings out of 6935 investigated tree rings. However frequency percentages are misleading at the low replicated beginning part of the record. Therefore, results are discussed for the 1750-2004 period only, where the number of samples exceeds 10 trees and where the major part of frost ring occurrences (57) was observed (*Figure 3*).

Mean age fluctuated between 50 and 165 yrs, standard deviation changed from 33 up to 93 yrs in the studied period.

We found concentrated occurrences of frost rings in three decades: in the 1790s, 1810s and 1910s.

No any frost ring appeared in two bidecadal periods: 1750-1770 and 1850-1870. The longest period without frost ring occurrence was between 1963 and 2004 in the analysed interval. The maximum of frost ring frequency percentage was 53% for the year of 1876 when 10 samples had a frost ring out of the 19 trees representing that year. The second prominent year was 1810 when 5 from 21 investigated trees have shown a frost ring.

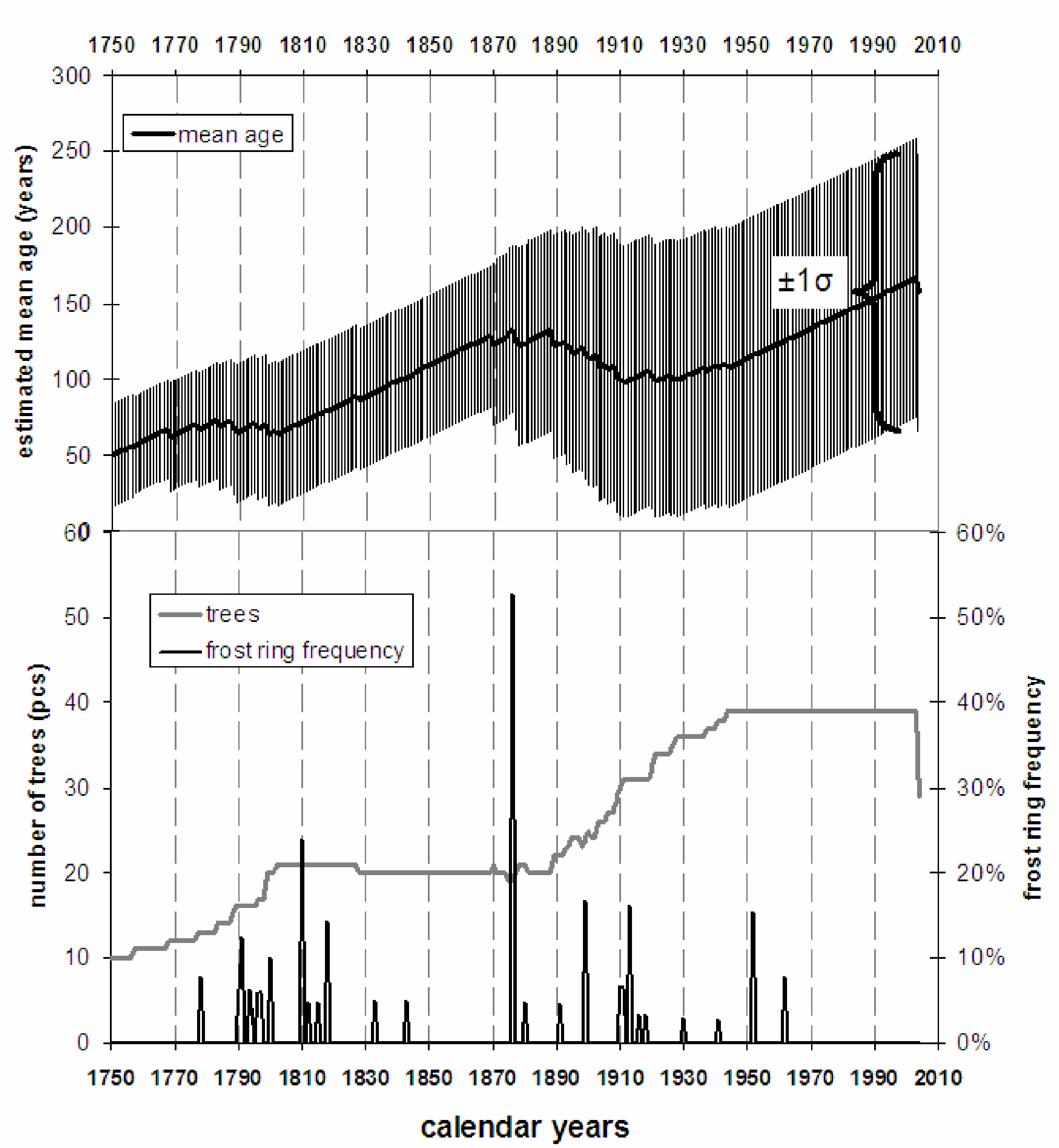

Figure 3. Fluctuation of mean age and its standard deviation (upper graph); frost ring frequency and sample number (lower graph) over the 1750-2004 period

3.2 Treeline

Two tree-form and four bush-like stone pine individuals were found in NW exposure being at highest elevation in their broader area. Arithmetic mean was calculated from individual elevation data within both groups (*Table 1*).

Table 1. Results of altimetry of tree-form and bush-like individuals in NW exposition at the highest elevations, uncorrected data (PDOP below 4 indicates precise measurement)

		Lat (°)	Lon (°)	Alt (m)	PDOP
dwarf-shape	1	47.098	25.238	1964	2.65
	2	47.098	25.238	1951	2.67
	3	47.100	25.236	1933	3.24
	4	47.104	25.259	1880	3.14
	mean			1932	
tree-shape	1	47.102	25.246	1865	2.09
	2	47.101	25.245	1868	2.05
	mean			1866	

4 DISCUSSION

4.1 Frost rings

Severity of frost events occurring in the vegetation season is evaluated from two viewpoints. The stronger the frost event, the higher the frost ring frequency in the stand and the elder specimens are affected (Popa et al. 2006).

The timberline in the Calimani Mts. has suffered the most drastic frost damage in 1876 since 1750. If our sample depth is representative for the stand, it means that frost rings developed in more than half of the trees. The frost ring containing tree ring with oldest observed cambial age (176) coincide with this event. Mature individuals older than 80 years of cambial age have been abundantly affected in that year.

Old diaries, newspapers and the meteorological yearbook reported late frost in the Carpathian region for the 19-21st May 1876 (*Table 2*). So the cold weather of those days must have caused the frost rings of stone pines (Popa et al. 2006).

The course of the pentad mean temperature anomalies (*Figure 4*) shows significantly different temporal evolution of meteorological preconditions causing the 1876 frost ring as Stahle (1991) (cited by Schweingruber 1996) found for post oak (*Quercus stellata* Wangenh.) from North America. Stahle (1991) reported above-average temperature sustained for 2 days at 10-12 days before the frost event. Our meteorological data show the highest positive anomalies one month before the frost event, which had to span more than two days because the vertex of the anomaly-curve existed for two pentads.

Except for the 1910s only single year frost events appear during the 20th century. The recent four decades without frost ring is the longest interval lacking evidence of frost lesion over the studied period. These findings indicate that after 1920 both frequency and severity of frost events seem to decrease in the region compared to the prior 170 years. The increasing estimated mean age of samples cannot explain this phenomenon because the corresponding standard deviation range widens indicating that young – frost sensitive – specimens were continuously represented in the period. It suggests that temperature drops during the vegetation period tend to show lower amplitudes becoming less effective in causing significant damage in the currently developing increment at the timberline. This experience is in agreement with the findings of Scheifinger et al. (2003). They found that the real risk of late frost damage for plants was lower in Central Europe during the 1990s as compared to the previous four decades. In addition, examining long instrumental temperature records Moberg et al. (2000) found a progressive reduction of about 7% of inter-daily variability of daily temperature index in all-seasons between 1880 and 1998 at four European stations.

Table 2. Reports about late frosts from 1876 in the broader Carpathian region

Late frost in May 1876	Location	Altitude above sea level (m)	Observation	Reference
19-20th, May	Sopron (Hungary)	224	Grapes frozen	Réthly 1998 pp. 542-543.
20th, May	Ungvár (now Uzhgorod, Ukraine)	129	-1.6°C in the morning	
21st, May	Taktabáj (Hungary)	95	Cereals, beans, potatoes frozen	
21st, May	Jászdózsa (Hungary)	100	Heavy frost	
19-21st, May	Sárospatak (Hungary)	126	Heavy frost	Schenzl 1878 pp.105-111.
21st, May	Csíksomlyó (now Şumleu, Romania)	707	Flowering trees frozen	
21st, May	Bakonybél (Hungary)	286	Flowering trees frozen	

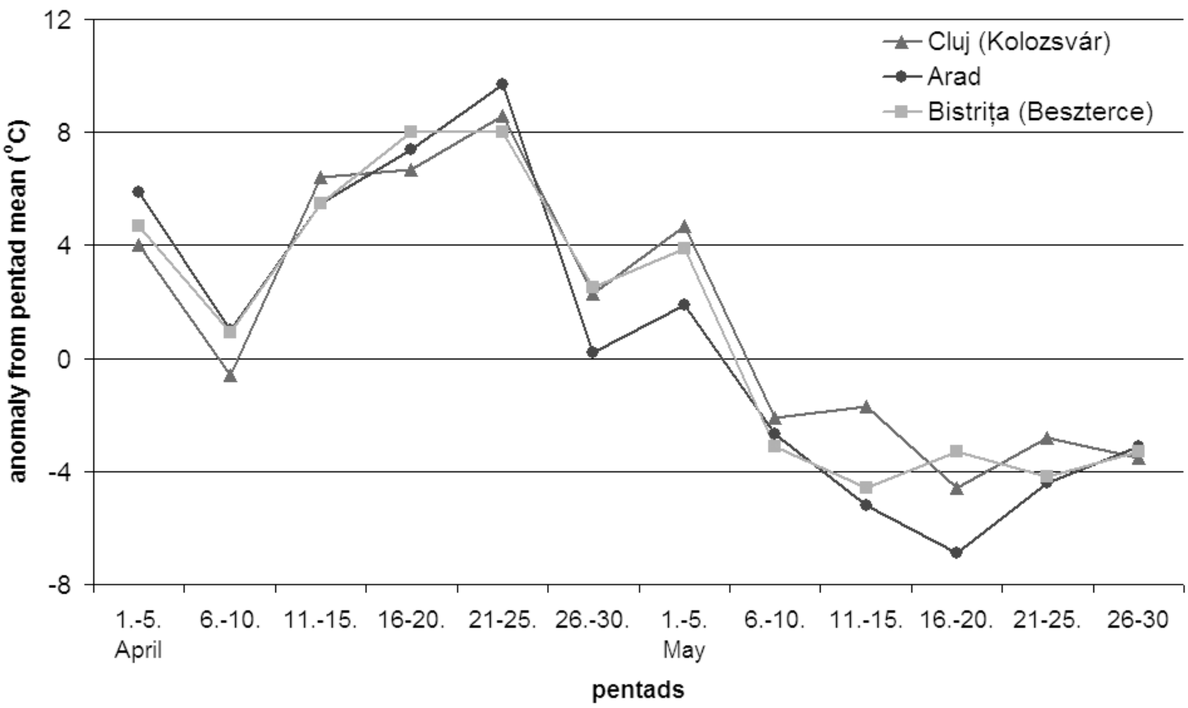

Figure 4. Anomalies of pentad mean temperature at Cluj, Arad and Bistrița stations between 01. April–30. May, 1876 (data from Schenzl (1878))

4.2 Treeline

For the determination of the elevation change we reduced the mean elevation data of tree-form and bush-like boundaries, uniformly, by the 30 m because of the overestimation bias of GPS measurements. Comparison of treeline data from old forestry survey to present-day corrected ones (*Table 3*) indicate significant upward migration. For the treeline position and bush-like occurrence boundary 65 m and 95 m rising was determined, respectively. In a similar study, Nicolussi et al. (2005) have observed 65 m upslope advance of stone pine treeline in the Ötztal Alps for the 1850-1980 period. Koch et al. (2004) found that treeline, dominated by mountain hemlock (*Tsuga mertensiana*) and subalpine fir (*Abies lasiocarpa*), has risen ~40 m over the last 100 years in Garibaldi Park, (Coast Range Mts., British Columbia). Mátyás (2006) reports a spruce treeline elevational shift in the Southern Urals between 60 and 80 m for the 1928-2000 period. Our results are in agreement with the trend and with the order of magnitude of above-mentioned data.

There are a few possible explanations for discrepancies. First, different species might react with different dynamics. Second, we cautiously avoided sample sites with visible human disturbance (Kern – Popa, 2007) but we cannot exclude that the sites of old forest inventory had anthropogenic influence. Another potential source of error might come from methodological differences between the 20th and 21st century surveys. Elevation data of the old forestry survey were barometrically determined and graphically corrected (Fekete 1902) while GPS determines the elevation above an ellipsoid which we corrected by the above described method.

The collected data support the hypothesis that changes in the frost ring record and migration of the treeline are closely related evidences of vegetation response to a recent regional environmental change. Decreasing frequency and severity of frost events indicate decreasing frost stress accompanied with warmer vegetation season for the timberline in the subalpine zone of the Calimani Mts. The observed upslope migration of altitudinal limit of tree-form and bush-like morphological groups of Swiss stone pine during the 20th century is in agreement with decreasing frost intensity, since milder conditions above the actual forest boundary provide an opportunity to colonize the higher elevated long-time treeless terrain.

Table 3. Centennial shift in the upper limit of tree-form and bush-like occurrences of stone pine in Calimani Mts. between 1910 and 2006 (in metres)

	Altitude of upper limit for	
	tree-form	bush-like
~ 1910 (Fekete, Blattny 1913)	1771	1807
2006 (*corrected data*)	1836	1902
„migration”	+65	+95

5 CONCLUSIONS

Tree-ring structure of 48 (39 living, 9 dead) stone pine trees were analysed from a 340 years long interval (1664-2004). Detailed discussion is restricted to the post-1750 period.

The timberline of Calimani Mts. has suffered the most drastic frost event in 1876 since 1750. After 1920 both frequency and severity of frost events seem to decrease compared to the prior 170 years.

Comparing treeline data from the old forest inventory of Fekete and Blattny to present-day (2006) data indicates a significant upward shift. A difference of 65 m and 95 m was established for treeline and boundary of bush-like occurence, respectively. This value is a bit higher than other published data but is in the same order of magnitude.

The observed upslope advance of tree-form and bush-like morphological groups of stone pine during the 20th century is probably related to the decreasing frost stress above the timberline zone documented by the frost ring record. So, less severe conditions above the forest boundary provide opportunities to colonize the long-time treeless terrains.

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