Dendroecological analysis of the influence of strong winds and snow accumulation on the growth of trees at the treeline in Vitosha Mountain, Bulgaria

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Introduction

As in other parts of Europe, the treeline position in the Bulgarian mountains has been affected by human action in the past. In certain regions such as the highest parts of Vitosha Mountain overexploitation and fires have destroyed a large part of the coniferous forests. In the 1940s their restoration has been started by afforestation. The forest authorities have taken the decision to use tree species that were found elsewhere in the Bulgarian subalpine forests. The most commonly used species were Macedonian pine (*Pinus peuce* Griseb.), Bosnian pine (*Pinus heldreichii* Christ), Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.) and to a limited extent the dwarf form of Mountain pine (*Pinus mugo* Turra ssp. *mugo*).

Currently the condition of these species enables a study of the differences in their resistance to the limiting factors at the treeline.

The natural treeline of Vitosha Mountain is situated below the potential thermal treeline, which is marked by the position of the 10°C July isotherm (Dakov et al. 1980). For Vitosha Mountain this isotherm lies at approximately 2000m a.s.l. whereas the treeline is at 1850m a.s.l. This is a clear sign that there are other limiting factors besides temperature. Vitosha Mountain is the second windiest mountain in Bulgaria and is characterized by large snow accumulations as a result of wind transport activity (Vekilska 1966). Stem deformations observed in afforestations suggest that these two factors (i.e. wind and snow accumulation) may be of primary importance.

An obstacle to the research on the relative importance of limiting factors in the region is that forest managers do not have accurate data from observations in these forests. This necessitates the use of methods which allow restoration of past events and collection of information about their influence. Dendroecological methods are particularly useful because they provide the possibility to analyze the effect of natural conditions on tree growth and, specifically, on the structure of tree rings (Fritts 1976, Schweingruber 1996)

Study Area

The chosen study site is the treeline that borders with a wide treeless plateau near Aleko hut at an altitude of 1850 m a.s.l. Three plots with area of 2000 m^2 have been set in *Pinus peuce* forests (Fig.1) The first plot (plot N1) was set in an afforestation that is isolated in front of the treeline forests and thus is exposed to the action of winds from all directions. The second one is at the treeline (plot N2) and the third one is in the forest stand behind the treeline (plot

N3). The trees in all of the plantations are at about the same age (approximately 60 years). Because of their proximity, plots are exposed to similar general climate conditions. Therefore, this design allows the responses to other limiting factors that act locally to be distinguished. The region is generally flat and exposed to strong winds. The mean annual temperature is 2.58°C. It ranges from a mean monthly temperature of -6.04°C in January to +11.54°C in August. Prevailing strong winds are Northwestern, Western and Southwestern.

Figure 1: Study area and position of the study plots

Methods

In order to obtain more information about the influence of strong winds and snow accumulations on the growth of trees at the Vitosha Mountain treeline, and test whether these could be the most important limiting factors, we have chosen to use dendroecological analysis.

In the study plots, H, Dbh and crown dimensions of the trees have been measured. In the treeline sites, trees have been separated in the following groups according to their stem and crown state:

1. trees with normal stems and crowns;
2. trees with normal stems and crowns, but with broken tops;
3. trees with broken stems (Figure 2a);
4. trees with strongly bent stems (Figure 2c);
5. trees that were bent near the base of the stem and have horizontal growth (Figure 2b) and
6. trees with inclined stems;

In the treeline sites (plots N1 and N2) coordinates of the trees were recorded and digital maps were built with the use of ArcGIS 8.3 software package.

Cores for dendroecological analysis were taken from trees of the different groups. The directions of the extraction of the cores were from (a) the side of bending and from (b) the opposite side. A total of 90 trees were sampled, 58 of which had stem deformations.

Ring widths were measured in the Dendrochronology laboratory at the University of Forestry in Sofia. Special attention was paid to rings with a structure that differed from the normal one.

This was done because such rings might be very helpful in crossdating procedures and could carry valuable information about the growth of the tree (Fritts 1976, Schweingruber 1996)


Figure 2a *Figure 2b* *Figure 2c*

Figure 2: Tree with a stem that was broken twice (2a); tree with a stem that was bent near the base and had consequent horizontal growth (2b) and tree with a strongly bent stem 2c)

The tree ring series were crossdated using the COFECHA software and visual clues in the ring structure (e.g. dated frost and light rings).

Cores that showed strong correlation were used for the composition of chronologies after a standardization procedure. For this process we used a modified exponential curve from the type $y=a\exp(-bx) + c$ (Cook et al. 1990). After the composition of the chronologies that carry the common signal of the climate influence, these chronologies were compared to the growth curves of trees with broken tops or stem damage. Thus we determined periods of stress, serious stem deformations, and the influence of top breakage on tree growth. Special attention was paid to the initiation of periods with formation of reaction wood for more than one year, which is considered an attempt by the tree to regain its vertical growth orientation after bending (Kwon et al. 2001). Data from plots with a significant number of trees with such response in a certain year were compared with climate data for winter precipitation to test for a possible relationship.

In 2003 and 2004, after storms, regular observations were carried in the plots in order to obtain more precise information for the influence of strong winds and snow accumulations. To obtain information for the snow accumulation and distribution in the winter of 2004 we carried out regular measurements of snow depths in plot N1 with the use of avalanche probe.

Results and discussion

Results from measurements of snow depths

The results from the measurements of snow depths in plot N1 in the winter of 2004 are shown on figure 3.

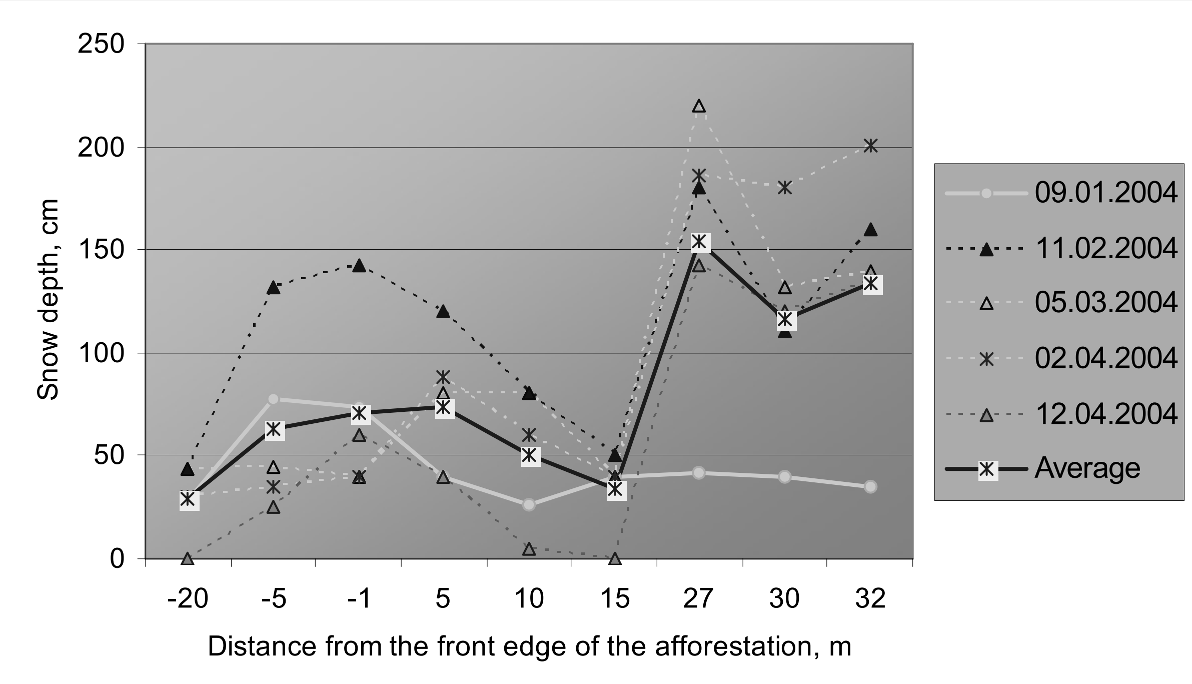

Figure 3: Snow depths in plot N1 in the winter of 2004.

As it can be seen from the figure above, at the beginning of the period of snow accumulation (09.01.2004), the snow cover is almost evenly distributed within the plot and in front of it. The next measurements show that there is a tendency of increase of the snow depth in proximity to the front edge of the plot and a slight decrease in the first 10m in the forest. Then at about 15m behind the front edge snow depths increase sharply to reach a maximum depth at a distance of about 25m behind the forest edge. The maximum snow depth, which was measured at the beginning of March, was 220cm. At the same time the snow depth on the flat plateau, 20m in front of the forest edge, was 50cm. This shows that snow transportation by wind plays a major role in distributing snow accumulation on Vitosha Mountain. Our results also show that snow accumulation is strongly influenced by the existing forest stands or groups.

Distribution of the trees in the plots according to their stem and crown form

As it has been shown on Figure 4 there is a zone with increased concentration of trees with broken, bent or horizontal stems and of dead trees in the middle of plot N1. Therefore we called that part of the plot “Mortality and disturbance zone”. There is a relationship between the position of this zone and the distribution of snow accumulation. As discussed above, the snow depths start increasing sharply 15 m behind the front edge of the afforestation, which coincides with the border of the “Mortality and disturbance zone”.

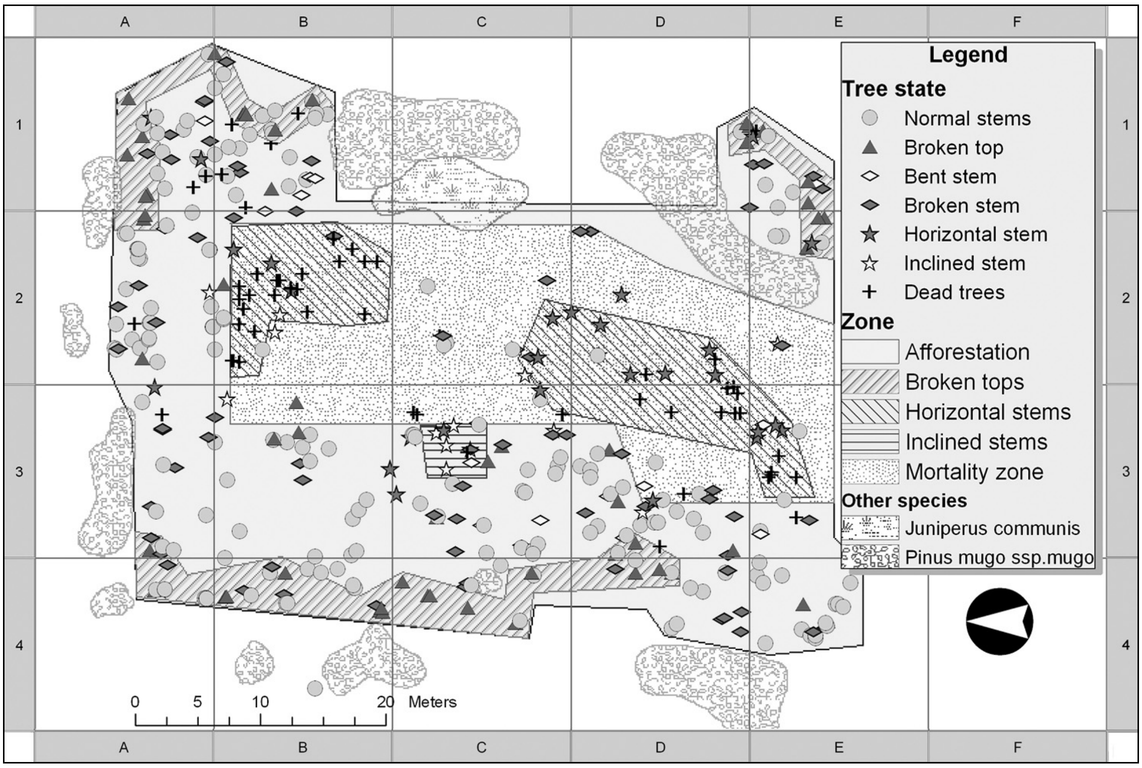

Figure 4: Map of the trees, stem, and crown deformation zones in plot N1

Almost the same distribution is observed in the other treeline plot – plot N2. Here, there is also a zone with increased concentration of trees with damaged stems and crowns, which starts at approximately 15m behind the forest edge.

It is known that dense forest borders decrease the speed of wind (Somerville 1980). Most probably, this causes increased snow deposition at a certain distance behind the edge. Snow loaded trees are more subject to stem damage during events of strong winds (Petty and Worrell 1981, Peltola et al. 1999). This, together with the large snow accumulations, explains the existence of the “Mortality and disturbance zones” in the plots.

Trees with broken tops are more frequently found at the forest edges (Figure 4). During field inspections, it was observed that very strong winds sometimes cause the breakage of the last 3 or 4 years of vertical increment. Thus, it is not surprising that there is an increased frequency of trees with broken tops in parts of afforestation characterized by highest wind speeds. Strong winds, or the combination of strong winds and snow or rime frost accumulation might also have caused the stem breakage of trees at the forest edge when they were younger. This is consistent with the existence near the forest edge of trees with stems that were broken once at height of up to 3m and then were successfully substituted by lower branches.

Influence of climate events on tree ring structure

During the observations and measurements of the tree rings, 13 types of tree ring structure were described which can be classified as differing from the normal one. Most frequent, and therefore important for the current research, were frost rings, light rings and rings with different types of reaction wood.

Frost rings were first described by Ratzburg in 1871 (ex Schweingruber 1996). Usually their formation has been associated with events of spring frosts or water stress (Stockli 1996). In the study site the frost rings formed in 1952, 1955 and 1962 were very frequent. The 1952 frost ring has a wide zone of distorted cells and is found in 80% to 85% of the cores from the different plots. The 1955 frost ring is less distinct with narrower zone of distorted cells and is found in 50% to 85% of the cores. The 1962 frost ring is quite peculiar. It has most probably been formed after a late frost event, which was caused by an unusually cold storm event at the beginning of June 1962. Thus, the beginning of the ring has normal cells, followed by a very dark layer of thin, crushed cells and a wide zone of distorted cells. This frost ring is found in 85% to 92% of the cores. The recurrence of these rings was very helpful for the crossdating of the samples, especially in cases of dead trees and trees with missing rings.

Several different types of reaction wood were observed in the samples. Reaction wood formed in a narrow band or at the end of the ring was considered a sign of mechanical influence on the tree during the growing period (Kwon et al. 2001, Dunker and Spiecker 2004). It had most probably been caused by strong wind. Reaction wood formed at the beginning of the tree ring or in the whole ring was considered a sign of mechanical influence on the tree during the autumn and winter period. Therefore it had probably been caused by strong winds or snow accumulation. A special case with *Pinus peuce* wood is the presence of large quantities of resin in some rings ("rings with resin spills"). This has also most probably been caused by mechanical damage or injury of the tree, since it is known that after such events some coniferous trees tend to produce more resin in an attempt to protect themselves from further damage (Schweingruber 1996). In plot N1, about 23% of the trees with damaged stems had initiated the formation of reaction wood in the entire ring in 1963 (Figure 5). These years coincide with the beginning of the period with highest winter precipitation recorded by the adjacent Cherni vrah weather station (Figure 6).

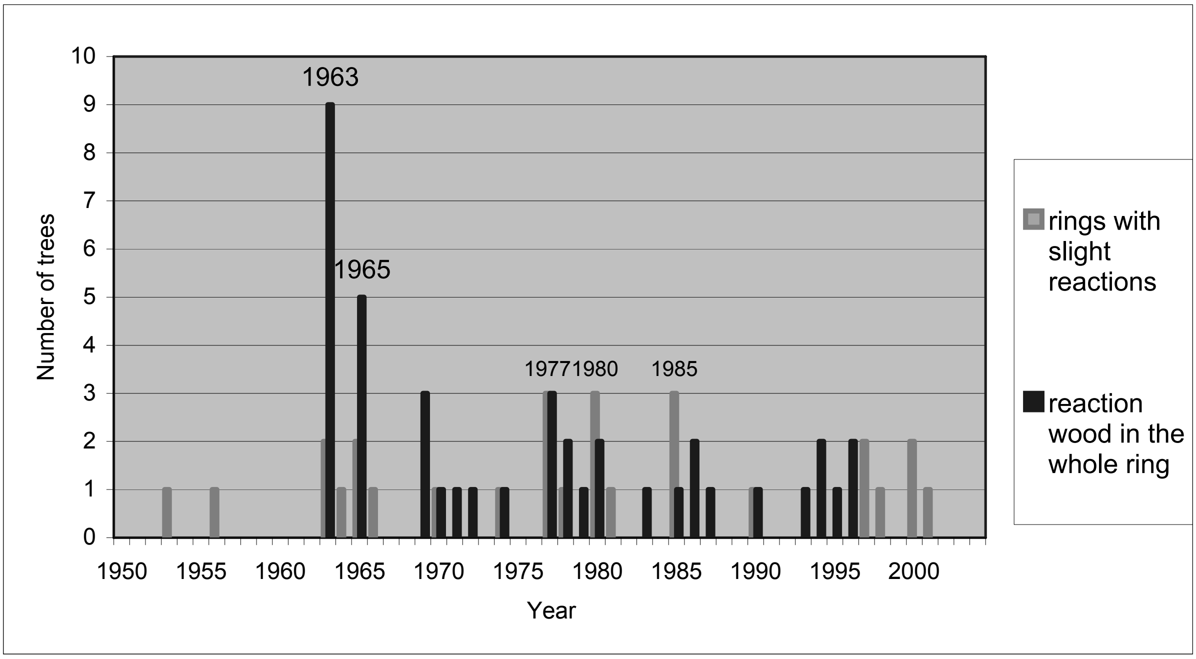

Figure 5: Initiation of periods with reaction wood in lee side cores from plot N1

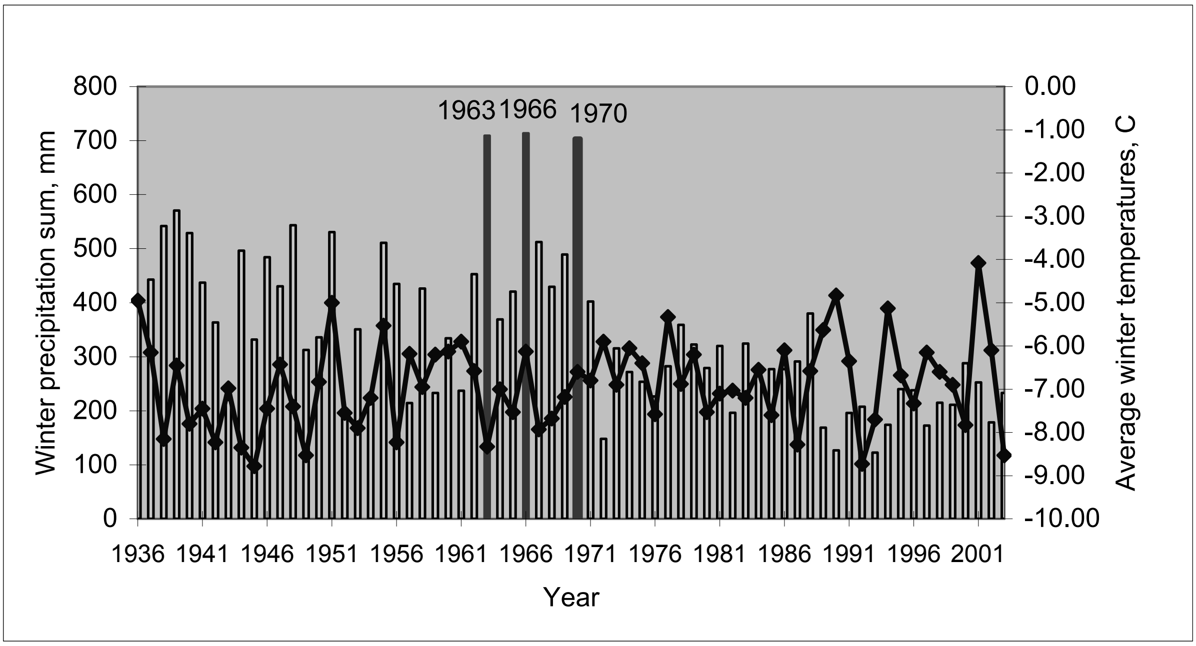

Figure 6: Average winter (December to March) precipitation (showed with columns) and winter temperatures (showed with line) recorded at the Cherni vrah weather station

In plot N2 the highest number of trees (40% of tested trees) that initiated the formation of reaction wood in the entire ring was also in 1963 (Figure 7). In plot N3, which is in the forest stand and is protected from higher snow accumulations due to wind transport, trees with reaction wood in the whole ring were just a few and there were no distinct years or periods with increase of this type of ring structure. This suggests that the observed situation in the treeline plots is closely related to the influence of extreme weather events such as strong gales, big snow and rime accumulations.

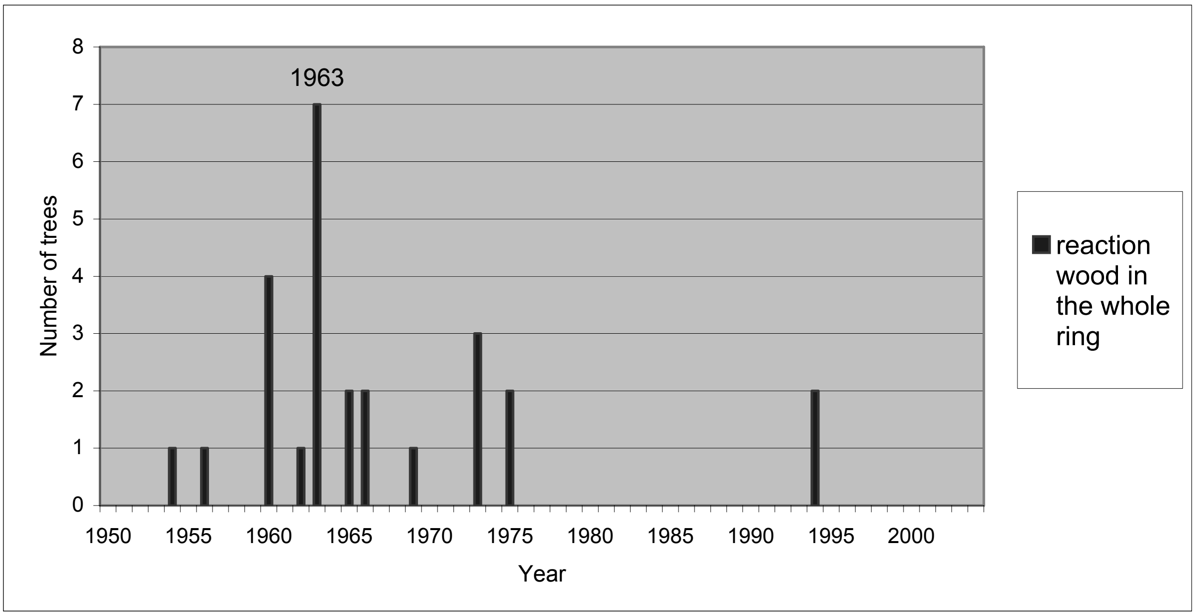

Figure 7: Initiation of periods with reaction wood in lee side cores from plot N2

It can be hypothesized that during the early development of the forest, when the trees in the "Mortality and disturbance zones" were small, their crowns and stems were damaged by large snow accumulations and strong winds. This disturbance has influenced their consequent development and these trees have grown inclined or even horizontally. The altered growth form has most probably been the reason for further damage in later years. Many of the trees in the "Mortality and disturbance zone" have been broken or bent repeatedly. This has caused the death of some of them, or at least has been the most important disturbance factor that has made the surviving trees susceptible to secondary fungal attacks. Currently, the existence of empty spaces at distances of one to two tree heights behind the forest edge contributes to additional snow accumulations and further stem damage of living trees.

Influence of top breakage on tree growth

Some studies (e.g. Larson 1964, Giertych 1964) show that cambial activity is dependent on the auxin production by the tree's apical meristems (ex Fritts, 1976). Thus, it could be expected that after top breakage, a tree would decrease its radial growth for a certain period of time. Keller and Lenz have observed this in a study of lopped spruce trees in 1970 (ex Schweingruber 1996).

The comparison of the individual growth curves of trees with broken tops (e.g. last 3 or 4 years of vertical increment) from plots N1 and N2 with the mean growth curves from trees with normal stems, showed that there is no serious radial growth decrease after the top breakage of *Pinus peuce* trees. We also did not find special reactions in the rings as indicators of the breakages, which is a further sign that they did not cause serious stress to the whole trees. This could be explained by the increased viability of young trees and the fact that Macedonian pine tends to rapidly substitute the broken top by a vertically orientated growth of a side branch (Dimitrov 1980).

Conclusions

The following major conclusions can be made from our results:

- Although *Pinus peuce* is one of the best-adapted species for the harsh growth conditions at the treeline zone in the highest Bulgarian mountains, some extreme climate events might have profound effect on the growth of certain individuals. In the region of Aleko hut in Vitosha mountain such events appear to be the strong winds and the large snow accumulations caused by wind transportation.
- In regions with strong winds and possibility for snow transportation it is not advisable to create afforestations with sharp forest edges, since this may be the reason for significant damage to the trees in a zone that begins at approximately 15m behind the forest edge.
- The breakage of the top of young *Pinus peuce* trees does not lead to a serious decrease in radial growth.
- Dendroecological methods might serve as a valuable tool in obtaining information for past events and their influence on the growth of trees, especially where there is limited historical information.

Acknowledgements

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