Alterations of Scots pine needle characteristics after severe weather conditions in south-eastern Estonia

Rein Drenkhan and Märt Hanso
Estonian Agricultural University, Institute of Forestry and Rural Engineering
Fr.R. Kreutzwaldi, 5, 51 014 Tartu, Estonia
Rein.Drenkhan@mail.ee, mart.hanso@eau.ee

Abstract

In the spring of 2003 massive deaths of Scots pine trees were registered on drought-sensitive oligotrophic sandy soils in south-east Estonia, together with the stress symptoms on some other tree species. Having at our disposal retrospective long-period data, obtained by the needle trace method (NTM) from three pine stands in south-east Estonia we decided to look into history, searching for seasons, meteorologically resembling the hard seasons of 2002/2003 (severe drought, abrupt winter onset and unusually cold first half of winter), and see how did NTM characteristics respond during last century: 1) to the similar seasons, and 2) to the most severe appropriate seasons. We concluded that none of the mentioned above hard seasons could, separately taken, cause the registered losses but, at the same time, resembling full series of seasons could not be found inside that period, which would be adequately covered by our NTM material.

Introduction

In 2001 a severe outbreak of *Gremmeniella abietina* was registered in stands and plantations of Scots pine (*Pinus sylvestris*) in Sweden (Wulff & Wahlheim 2002) and in eastern Norway (Solheim 2001). In the same year (2001) Scots pine plantations in South Estonia experienced a hard epidemic of *Lophodermium seditiosum* (Hanso & Hanso 2001). In the spring 2002 some concern of a start of a new epidemic of *G. abietina* was expressed in north-eastern part of Estonia (in Sirgala, fig.1), as after a 37-year-long break the perfect stage fruitbodies of the pathogen were found again in Estonia (Hanso & Hanso 2003). *Gremmeniella abietina* teleomorphs had been registered during the first diagnosed epidemic in Estonia, i.e. during the hardest epidemic of the disease in 1964–1965 (Hanso 1969, 1973). During that long break only anamorph (*Brunchorstia*-) stage fruiting of the fungus was observed in forest pathological surveys. Also news about the recent outbreak of *Gremmeniella* in Scandinavia had to be considered seriously as well on the eastern coast of the Baltic Sea.

Fig. 1. Locations of a suspected epicentre of a new G. abietina *epidemic in Sirgala in 2002, the severely damaged young pine plantations in 2003 in Liiva and Loosi, and the pine stands examined by needle trace method (NTM) in Konguta, which served as the source of retrospective long-period NTM material.*

Health condition of the forests of south-eastern Estonia in spring 2003

In the spring 2003 a large-scale death of Scots pine trees in plantations and stands of south-eastern Estonia, especially devastating on drought-sensitive sandy soils (e.g. in Liiva and Loosi, fig. 1), was registered by local forest authorities, who preliminarily attributed the damage to *G. abietina*. After careful diagnostic work (Hanso, unpubl.) it was ascertained that the death of pines was not caused by *G. abietina* or by any other well-known infectious disease.

Concerning health condition of other native forest-forming tree species in south-eastern Estonia in the spring of 2003, Norway spruce (*Picea abies*) had not been seriously affected, but aspen trees (*Populus tremula*) showed abnormal shoot swellings and started to loose their leaves abnormally early, however, without visible fatal results to the trees. Additionally, a sudden death was registered in the stands of some exotic tree species (e.g. *Pseudotsuga* sp.).

In 2002 the weather was very special in Estonia, with a severe and long drought in the summer and autumn followed by an unusually cold winter. A diagram presentation of this weather data (figs. 2 and 3) revealed a third exciting peculiarity of the year 2002, an extremely abrupt autumn in comparison with the long-period mean (fig. 2).

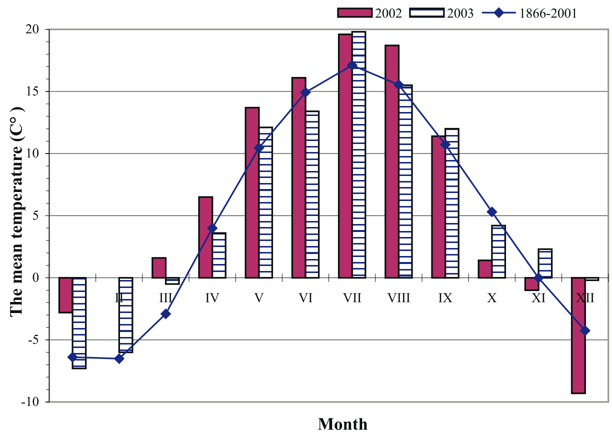

Fig. 2. The mean monthly temperatures in 2002 and 2003 (in columns) together with the long period (1866–2001) mean (curved line)

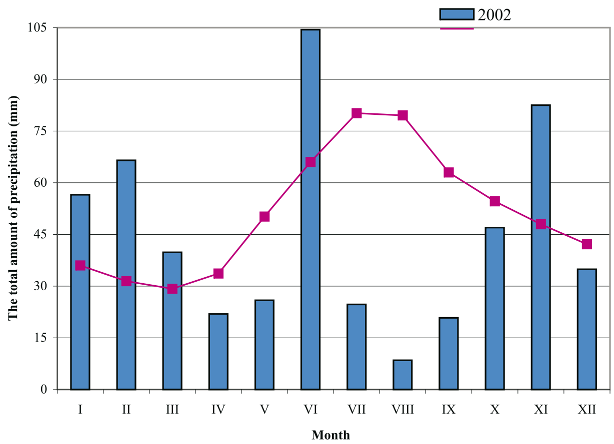

Fig. 3. The sums of monthly precipitation in 2002 (in columns) together with the long period (1866–2001) mean (curved line)

Scots pine seemed to be more stressed than other forest-forming native tree species in south-eastern Estonia in the spring of 2003. Although Scots pine has been classified in Estonia (Laas 1967) as a cold- and drought-resistant tree species, the decisive factor for the annual ring index variation of Scots pine appears to be the temperature of the winter prior to the growing season, but also the mean deficiency in air humidity in June-August has a relatively high correlation with the annual ring index variation (Lõhmus 1992). In other words, Scots pine in Estonia is not indifferent towards hard winters and summer droughts.

Strength of the climate correlations can be increased and the range of extractable parameters extended by including dendrochronology with the different other proxies (McCarroll *et al.* 2003). Long chronologies describing retrospectively different needle characteristics of pines can be drafted using NTM (Needle Trace Method, cf. Kurkela & Jalkanen 1990). Fortunately we had access to long retrospective time-series based on the needle trace method and describing the behaviour of pine in the continuously changing environment of Estonia. This dataset was now used to examine whether the massive death of Scots pine could be explained by climatic factors.

Material and methods

Since we had access to the retrospective long-period (1884–1944 and 1957–1995) NTM material from three Scots pine stands in south-eastern Estonia, analysed by Drenkhan (2002), we decided to look for answers to the recent problems from the past, i.e. to investigate how Scots pine needle characteristics have altered within long period during the first years after seasons with following description:

1. Extreme (dry or cold, respectively) seasons;
2. Seasons meteorologically resembling the summer of 2002 and the winter of 2002/2003, respectively and separately taken (i.e. not in succession).

If the needle characteristics of Scots pine respond to the extreme and long lasting meteorological events (the used meteorological characteristics were the mean air temperature and the sum of precipitation of the appropriate month and/or season), we could attribute the recent massive stress and death of pines in south-eastern Estonia to the meteorological peculiarities of the summer 2002 or the following winter 2002/2003.

It is not known during how many dry summers or how many cold winters within the experimental period the tolerance level of Scots pine was exceeded in such a way that it is reflected in the needle characteristics. Therefore two samples of extreme seasons were chosen from history:

1. 3 years. Alterations in the needle characteristics of pine can be surely caused as well by several other agents in addition to the meteorological extremes and therefore the sample of 3 years is too small.
2. 10 years. If Scots pine would suffer during so many years per century, it would have not been classified to the drought- and cold-resistant tree species.

Therefore the samples consisting of both 3 and 10 declining years were provisionally taken and used to examine closer the correct number of extreme years during which the tolerance level of Scots pine was exceeded.

First we computed mean values of the three different needle characteristics of Scots pines (needle retention, needle age and needle loss, cf. Aalto & Jalkanen 2004) for the period covered by our NTM data and conditionally named «the century». After that these mean values were calculated for the following years within the experimental period:

1. For the three/ten years, which had the highest mean air temperatures of the summer months (from May to September, incl.);

2. For the three/ten years, which had the lowest mean sums of precipitation per the summer months;
3. For the three/ten years, which had the lowest mean air temperatures of the winter months (from previous year December to subsequent year March, incl.).

The possible influence of random agents to the needle characteristics would hopefully be smaller in the ten-year sample. The calendar years selected are shown in Table 1.

Table 1. The definite calendar years, belonging to the different sample sets

Sample sets of the years, regarding							
high mean summer (V-IX) temperature, °C		poor mean summer (V-IX) precipitations, mm			low mean winter (XII-III) temperature, °C		
3 hottest summers	10 hot summers	3 dry summers, similar to 2002	3 driest summers	10 dry summers	3 cold winters, similar to 2002	3 coldest winters	10 cold winters
1934	1901	1913	1901	1901	1902	1893	1888
1936	1920	1964	1939	1913	1909	1940	1893
1937	1932	1976	1976	1939	1912	1942**	1917
2002*	1934	2002*		1941	2002*	1963	1929
	1936			1958			1940
	1937			1964			1942**
	1938			1965			1963
	1939			1971			1970
	1963			1975			1979
	1972			1976			1985
							1987

* The summer 2002 belonged to the 3 most extreme seasons, but was not covered by our NTM data.

** The coldest winter in 1942 was covered by our NTM data but fell out of NTMeng computations for the peculiarity of the program.

By this way we obtained information on the extent (or at least the directions) of alterations in the needle characteristics following severe meteorological conditions of summer or winter. To answer the question «Could the two seasons of 2002/2003, summer and winter separately taken and both clearly deviating from the long-period mean, cause the stress and death of pines in the south-eastern Estonia?» we found three years inside that long period, which resembled the most the summer of 2002 or the winter of 2002/2003, respectively. Then we computed similarly the corresponding mean needle characteristics for this set of years. Comparison of the alterations in needle characteristics among these three samples of years (in short: the extreme, the hard and the similar to 2002/2003 sample) should hopefully give us the answer to the question raised above.

Understanding tree physiology is complicated by the fact that the performance in a given year depends on conditions of previous seasons (James *et al.* 1994). The visible reaction of trees to an unfavourable (i.e. stressing) environment is often temporally delayed, and by the time when the visible symptoms occur (and when the pathologist arrives and becomes involved, cf. Houston 1987), the causative agent may be already absent. Therefore the alterations in needle characteristics were examined one, two and three years after the appropriate pointer year with extreme weather conditions. In the ideal case this 3-year-long period might cover as well a temporal aspect and reveal the peculiarities of the dying apart of the influence of the stressing agent. This period cannot be extended as the retention period of a Scots pine needle set in Estonia rarely exceeds three years (Tullus 1991; Drenkhan & Hanso 2000; Drenkhan *et al.* 2006).

Meteorological data were obtained from the Tartu-Tõravere Meteorological Station, which is situated ca 15 km from the pine stands in Konguta investigated by NTM (fig. 1), from the Institute of Meteorology and Hydrology (Tallinn), from the Võru Meteorological Station and from the data represented in the paper of A. Tarand (2003). NTM data were calculated by a special program NTMeng (Aalto & Jalkanen 2004). Statistical analyses were carried out by MS Excel and statistical program SAS.

Results and discussion

In this investigation the possible influence of the long and hard drought of the summer 2002 and the abnormally cold winter 2002/2003, separately taken, on the alteration of the NTM characteristics were examined. Research work, concerning the influence of abrupt winter onset 2002 on the alterations of NTM characteristics is still in process and the results are not included in this investigation, and only some meteorological data, emphasizing the extremity of the winter onset 2002, are shortly represented.

The cold winter

As mentioned above, the first symptoms of the massive death of pines became visible in the spring of 2003, immediately after the abnormally cold winter. The analysis of the alterations in needle characteristics after three different samples of winters is represented in Fig. 4. After three winters similar to the 2002/2003 winter the mean values of the characteristics needle retention and needle age apparently (although not statistically significantly) increased, while needle loss decreased. After the extreme (the sample of 3 record-cold winters, column 5) or hard (the sample of 10 coldest winters, incl. the full sample of record-cold winters, column 4) winters, the characteristics needle retention and needle age mostly decreased (with several statistically significant differences in mean values), as did also needle loss, although without significant differences. On the basis of the clearly different directions of the alterations of the needle characteristics after the extreme and hard winters, in comparison with the similar to 2002/2003 winters, we conclude that the weather conditions of the winter 2002/2003 are not the reason for the massive pine death in 2003.

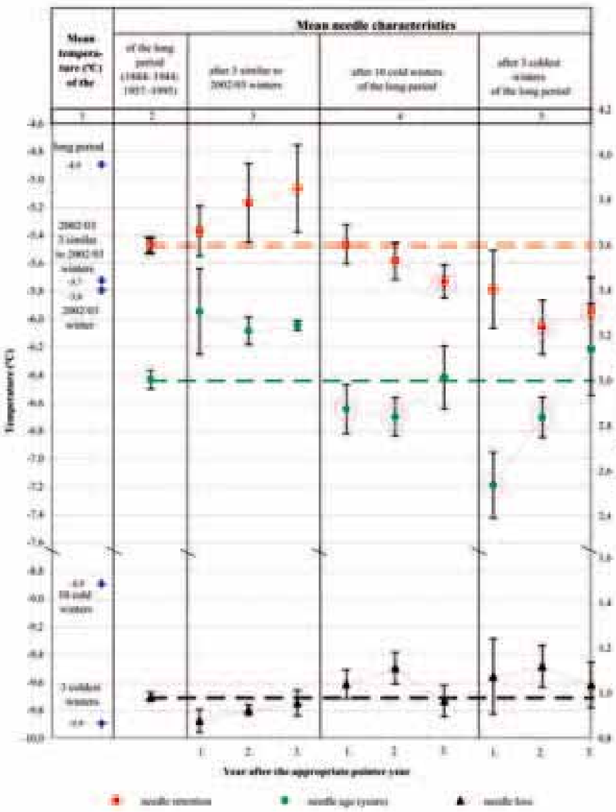

Fig. 4. A comparison of the mean temperature, radial growth and needle characteristics during the long period (1884–1944, 1957–1995) and during the first, second and third year, respectively, after 3 winters similar to 2002/2003, after 10 cold and after 3 coldest winters within the period. Pink circles show statistically significant differences.

The dry summer

The dry summer 2002 preceded the already characterised cold winter. As we have still no access to the computation methods of Palmer drought index, the influence of drought was analysed indirectly on the basis of summer air temperatures and summer precipitation, taken as separately.

The summer 2002 proved to be one of the three hottest summers of the long period. The reason why it is absent from the list of respective sample set of years (Table 1) is, that we had no NTM data for the year 2002. As one can see from the Fig. 5 (column 1), the mean air temperature of the summer months of 2002 was higher than the mean temperature of the sample set of 3 years inside the century with the warmest summer months. Regarding the needle characteristics, only two values were statistically significant, the characteristic needle retention in the first year after the three hottest summers and needle age in the first year after the 10 hot summers of the century. We propose that the weather conditions of summer 2002, though not lethal, could have stressed the trees.

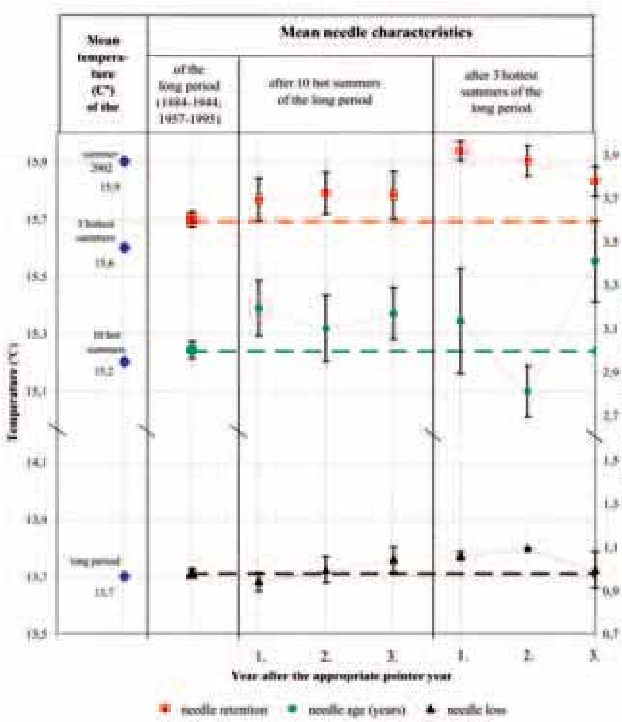

Fig. 5. A comparison of the mean temperature, radial growth and needle characteristics during the long period (1884–1944, 1957–1995) and during the first, second and third year, respectively, after 10 hot summers and after 3 hottest summers within the period. Pink circles show statistically significant differences.

One more figure (not represented in this paper) was constructed by the same way as figures 4 and 5, but concerning the alterations of NTM characteristics after the driest (regarding the sums of precipitation per summer months) and similar to the summer 2002 years. Although none of the alterations occurred were statistically significant, some directions of the alterations were noteworthy.

The abrupt winter onset

Concerning meteorological peculiarities, the autumn (winter onset) 2002 was the most extreme (Table 2) among the seasons under the investigation. Figure 6 shows the way in which the extremely short autumns inside the long period were computed for three meteorological stations in different counties (towns) of Estonia. Autumn 2002 belonged to the group of extremely abrupt autumns in all three meteorological stations – Tallinn, Tartu and Võru, but in the south-easternmost county of Estonia (Võru) this year (2002) was the absolute record-year (Table 2).

Table 2. Extremely short autumns within the experimental period, and covered by our NTM data (1884-1944 and 1957-1995). Using the temperature datasets of three meteorological stations (Tallinn, Tartu and Võru), the autumn (winter onset) was defined in three different ways, «autumn» extending from August to October, from August to November or from August to December,

Order of the coldest years	August-October			August-November			August-December		
	Tallinn	**Tartu**	**Võru**	**Tallinn**	**Tartu**	**Võru**	**Tallinn***	**Tartu**	**Võru**
1.	1939	1939	1939	1774	1882	**2002**	1788	1876	**2002**
2.	**2002**	**2002**	**2002**	1786	1941	1939	1803	**2002**	1939
3.	1912	1912	1976	**2002**	**2002**	1993	1759/**2002**	1882	1927

*The year 2002 was on the forth place

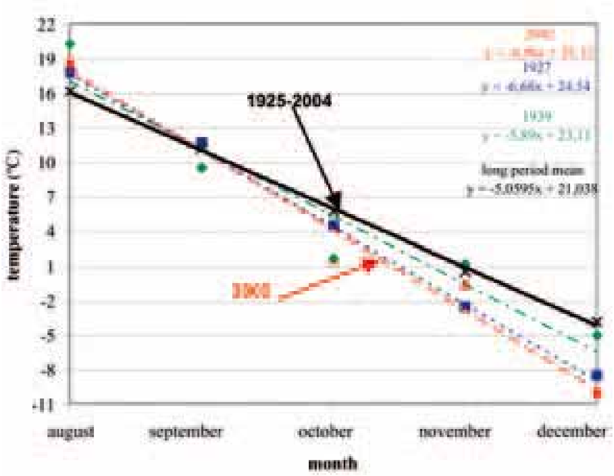

Fig. 6. An example of the computations for finding the most abrupt autumns among the years within the period 1884–1944 and 1957–1995, and calculated on the basis of the fall of mean air temperatures during the appropriate months

The directions of alterations in needle characteristics

Apparently due to the limited NTM material used in this investigation, several data represented in figures as numerical values did not differ statistically. However, if the directions of alteration were similar during all the three years following the pointer (presumably stressing) year, this characteristic direction could be taken more seriously (Table 3).

Table 3. The directions of alterations of the examined NTM characteristics and the radial growth after the hard periods (Pink colour shows statistically significant differences)

Characteristic	Winter	Summer temperature	Summer precipitation
Needle retention	↓	↑	↑
Needle age	↓	Undefinite	Undefinite
Needle loss	↑	↑	Undefinite
Radial increment	↓	↓	↓

Comparing the direction of alterations of NTM characteristics with the direction of alterations in radial increment showed that the former opened much more room for interpretation of pine reactions to the hard environmental conditions than the radial increment, which forms the basis of the dendrochronological method.

Conclusion

The directions and extent of alterations of the NTM characteristics (needle retention, needle age and needle loss) after the abnormally cold winter of 2002/2003, together with hot summer characterised by low precipitation, indicate that the particular unfavourable weather conditions could not act, separately taken, as the reason for the massive stress and death of pines registered in south-eastern counties of Estonia in the spring of 2003. However, although Scots pine is considered to be a cold- and drought-resistant tree species in Estonia, the sequence of adverse environmental events, which began with the hard epidemic of *Lophodermium* needle cast in 2001, and was followed by the dry summer of 2002 and ended by the abrupt autumn of 2002 and abnormally cold winter of 2002/2003, most probably exceeded the tolerance level of a number of pines, this series of events acting as a hard stress factor and leading to the massive death among pines.

Involvement of NTM data in the diagnostic trial of a complex pathological case was now undertaken for the first time, this approach opening new possibilities for the use of this method in forest science.

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