Retrospective Analysis of *Lophodermium seditiosum* Epidemics in Estonia

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Abstract – The needle trace method (NTM), created and developed by the Finnish forest pathologists prof. T. Kurkela, dr. R. Jalkanen and T. Aalto during the last decade of the XX century, has been already used by several researchers of different countries for retrospective analysis of needle diseases (*Hypodermella sulcigena*, by R. Jalkanen et al. in Finland) or herbivorous insect pests of Scots pine (*Diprion* pini, by T. Kurkela et al. in Finland; *Bupalus piniaria*, by H. Armour et al. in Scotland), but as well of pests of Sitka spruce (*Gilpinia hercyniae*, by D.T. Williams et al. in England). Scots pine in forest nurseries and young plantations of Estonia is often but irregularly suffering from the epidemics of the needle cast fungus *Lophodermium seditiosum*. Current environmental regulations exclude from the regulatory (control) measures all the others except of well-argued prophylactic systems, built up on reliable prognoses. The last is inconceivable without the availability of a reliable, as well, and long-lasting retrospective time-series of *L. seditiosum* epidemics, which, as it is known from the last half of the XX century, are occupying large forest areas, usually not least than a half of (the small) Estonia. An appropriate time-series would be useful, as well, for the more basic understanding of the accelerated mortality processes during the stand formation in early pole-age Scots pine plantations. Methodological principles of the use of NTM in an appropriate investigation together with the preliminary results of our research work, looking back for more than a century, are introduced and discussed in this investigation.

needle trace method (NTM) / needle diseases / annual needle loss / *Lophodermium seditiosum* / *Pinus sylvestris* / *P. contorta*

Kivonat – A *Lophodermium seditiosum* járványok visszatekintő elemzése Észtországban. A tűnyomok módszerét (NTM) finnországi kutatók (T. Kurkela, R. Jalkanen és T. Aalto) fejlesztették ki a XX. század utolsó évtizedében. Különböző országokban több kutató alkalmazta a tűbetegségek (*Hypodermella sulcigena*, R. Jalkanen et al. Finnországban), az erdeifenyő rovarkárosítások (*Diprion* pini, T. Kurkela et al. Finnországban; *Bupalus piniaria*, H. Armour et al. Skóciában), a szitkaluc károsítások (*Gilpinia hercyniae*, by D.T. Williams et al. Angliában) utólagos elemzésére. A tűkarc gomba (*Lophodermium seditiosum*) gyakran, de nem rendszeresen támadja az erdeifenyőt az észtországi csemetekertekben és fiatal erdősítésekben. A jelenlegi környezetvédelmi szabályok kizárják a védekezési módszereket, a megbízható előrejelzésen alapuló, jól megindokolt megelőző rendszerek kivételével. Ez utóbbiakhoz elengedhetetlen, hogy rendelkezzünk a *L. seditiosum* járványok megbízható, és hosszú távra visszatekintő idősoraival. E járványok a múlt század második felében nagy, rendszerint fél Észtországnyi területeket sújtottak. Egy megfelelő idősor hasznos lehet a felgyorsult pusztulási folyamatok alaposabb megértéséhez is az erdeifenyő erdősítések állománnyá

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alakulása során. Bemutatjuk és megvitatjuk az NTM alkalmazásának metodológiai elveit, kutatómunkánk több mint egy évszázadra visszatekintő előzetes eredményeivel együtt.

tűnyomok módszere (NTC) / tűbetegségek / éves tűvesztés / *Lophodermium seditiosum* / *Pinus sylvestris* / *P. contorta*

1 INTRODUCTION

Scots pine (*Pinus sylvestris* L.) is one of the main commercial tree species in Estonia, growing here in congenial to this species environment – climate and soils. The most common foliage disease in young Scots pine (*Pinus sylvestris* L.) plantations and forest nurseries of Estonia is caused by *Lophodermium seditiosum* Minter, Staley and Millar (*Rhytismatales*, *Ascomycota*). Occurrence of the needle cast disease and the disease agent (historically: *Lophodermium pinastri*) on the territory of Estonia was first documented at the turn of the XIX-XX century, both nearly at the same time, by the Baltic German foresters (Weiß 1902) and mycologists (Vestergren 1903), respectively. In Germany the problem of *Lophodermium* needle cast ("Kiefernschütte") had risen for the first time ca 50 years before, accompanying the beginning of the large-scale afforestations of the cutted areas by the use of nursery-grown pine seedlings (Stein, 1852. Thar. Forstl. Jahrb., Bd. 8; Holzner, 1877. Die Beobachtungen über die Schütte der Kiefer. Freiburg).

By today we know, that: 1) *Lophodermium* needle cast epidemics occur in Estonia almost regularly, but not precisely after definite intervals, and 2) needle cast epidemics are much more frequent in forest nurseries than in plantations, sometimes so frequent that the successive epidemics can not be distinguished from each other.

Still ignoring the possibility of genetic improvement of the pathogens virulence before the next-in-order epidemic, the explanation for the rise of a new epidemic has been still behold solely in the peculiar meteorological preconditions - rainy summers and following mild winters - of the years before the epidemics.

2 MATERIAL AND METHODS

2.1 Time-series and additional data sources

In this investigation we followed the traditional approach in the explaining of causes of the epidemics, i.e. considering the meteorological conditions of the preceding years. We tried to specify retrospectively the potential epidemic years of *Lophodermium* needle cast by juxtaposing two time-series: 1) the meteorological data (by selecting out the years with rainy summer + mild winter), and 2) the needle characteristic (extensive needle loss of the year, behold as a potential epidemic year).

This experimental approach could become possible only after the discovering and developing of the needle trace method (NTM, short description will follow) by the Finnish forest pathologists prof. T. Kurkela, dr. R. Jalkanen and T. Aalto (Kurkela and Jalkanen 1990, Aalto and Jalkanen 1996, 1998).

All available published data on the occurrence of *Lophodermium* needle cast disease during the last century in Estonia were used as additional sources for comparison with our experimental results with the purpose to make up the retrospective list of the disease epidemics.

During more than 40 years the elder author (M. Hanso) had carried out several investigations (Hanso, 1963, 1968, 1970, 2001, 2003) about the biology, ecology and regulation (control) of *Lophodermium* needle cast fungus and the disease, respectively, on pine. Additionally, his laboratory served in the years from 1972 to 1985 as the diagnostic centre for the whole forest nursery management system in Estonia. All the appropriate materials were used in this investigation, as the additional data.

2.2 Experimental study areas

The retrospective NTM data were obtained from six pine stands, of which four *Pinus sylvestris* stands were growing in Konguta, Elva Forest District, south-eastern Estonia, but two stands (*P. sylvestris* and *P. contorta*, respectively) in Järvselja Training and Experimental Forestry District (*Figure 1*). Eight model pine trees from stand 1 (situated at 58°13’ N, 26°10’E) were 109–115 years, eight trees from the stand 2 (58°12’ N, 26°08’ E) - 95-105 years old. The area of stand 2 had been more than a century ago in agricultural use. Eight model trees from stand 3 (58°16’ N, 27°19’ E) were ca 70 years old. The age of three model trees from stand 4 (neighbouring to stand 1) was about 45-50 years. Stand 5 (neighbouring to stands 1 and 4 from the other side) is a Scots pine provenance experiment and the age of altogether 68 model trees was 14 years. The age of eight model trees (*P. contorta*) from stand 6 (neighbouring to stand 3) was about 60-70 years. All stands were established by planting. All sample trees were growing in the main storey, each had a straight healthy stem.

Figure 1. Location of the investigated by the needle trace method (NTM) stands of Pinus sylvestris (in Konguta and Järvselja) and P. contorta (in Järvselja), and location of the meteorological station (Tõravere).

NTM data from the *P. contorta* stand were included, as this pine species was considered to be resistant to *Lophodermium* needle cast. Comparison of the needle cast dynamics in *P. contorta* and *P. sylvestris* stands could hopefully serve therefore as an additional argument in making decisions, e.g., was a hard needle loss in *P. sylvestris* stand caused by *Lophodermium* needle cast or by some other, more universal agents.

In this work an epidemic has been defined as any increase of disease in a population (Agrios 2005). The term “needle” actually means the term “fascicle” (or “short shoot”), less used in forest pathology than in plant anatomy.

2.3 Meteorological data

Meteorological data were obtained from the Tartu-Tõravere Meteorological Station, which is situated nearly between the investigated stands (*Figure 1*). For comparisons with the appropriate meteorological characteristics of the interesting us years ("pointer years") the long-period (1884-2004) mean monthly temperatures and precipitation sums were calculated first.

The pathogen needs both, the high precipitation for successful infection of pine needles in summer and the mild winter for successful colonisation of infected needles before the new vegetation of pine.

This way the potential *Lophodermium* needle cast epidemic years were considered to be probable, if the combination of wet (and warm?) summers and following mild winters will be met before the years of high needle loss. Epidemics of other infectious needle diseases of pine are rear in Estonia, but insect pests are triggered, on the contrary, by warm and dry summers.
Regarding the meteorological conditions, eight combinations of summers (between May and September) and following winters (from the previous year December to the pointer year March), were taken into the calculations to find out, which combinations were followed by the high needle loss in the next year. A year was classified as a “high precipitation” year and the following winter as a “mild” winter, if they were characterized by higher values of the respective meteorological characteristics, than the long-period (1882-2004) means +/- standard errors of the appropriate means.

Inside all the 8 combinations, higher (compared to long period mean, p<0,001) annual needle loss values followed the years with high precipitation in the period from:

a) July to September (VII-IX) + mild winter, and
b) July to August (VII-VIII) + mild winter.

Summer warmth, at the same time and concerning the same combinations of months inside “summer” (i.e.: a and b) had no effect on the amount of needle loss in the next (pointer) year, with no statistical differences between the warmer years and long period mean.

2.4 NTM analysis

One hundred and three sample trees from six pine stands were chosen and analysed according to NTM protocols (Aalto and Jalkanen 1998), including 95 sample trees of *Pinus sylvestris* and 8 of *P. contorta*. According to NTM protocols, a stand is already sufficiently represented by 5 to 10 model trees per age class (Jalkanen at al. 2000). Only 3 sample trees were analysed from the stand 4, which means that in our list the years 1958-1980 are represented insufficiently. The periods 1926-1937 and 1981-1994 are still not covered by NTM analysis at all.

After selecting out in a stand and felling of a sample tree the total height and annual height increments (the distances between the neighbouring branch whorls) were measured. From every annual shoot a 10-25 cm long section (bolt) was cut off. The western, northern and southern sides of each bolt were removed by axe already in forest, and only eastern side was transported to and analysed in laboratory according to NTM. Although all the bolts were marked (numbered), the full eastern side served for the control of the correct bolt age, i.e. the definite calendar year, as well. In laboratory, before the analyzes, only ten innermost rings of each bolt were left intact, because needles never keep attached to pine stem longer than 10 years (in Estonia they stay normally only 2.0 – 3.0 years).
One disk per every sample tree was sawed from the main stem for measuring the annual radial increments.

Needle trace method (NTM) was created for retrospective uncovering of different needle characteristics, from which only the characteristic "needle loss" was used in this investigation. NTM is based on the fact that the short shoots of living conifer needles remain attached to the pith of the main stem through the vascular tissue (Kurkela – Jalkanen 1990; Jalkanen – Kurkela 1992; Williams et al. 2003). The vascular connection extends through the each tree-ring, leaving there a trace for so long time as the needle is alive and functioning (*Figure 2*). When the needle dies the needle trace stops growing (into the next year ring). A needle trace is observed as a brown dot on the surface of the wood and can be seen with naked eye.

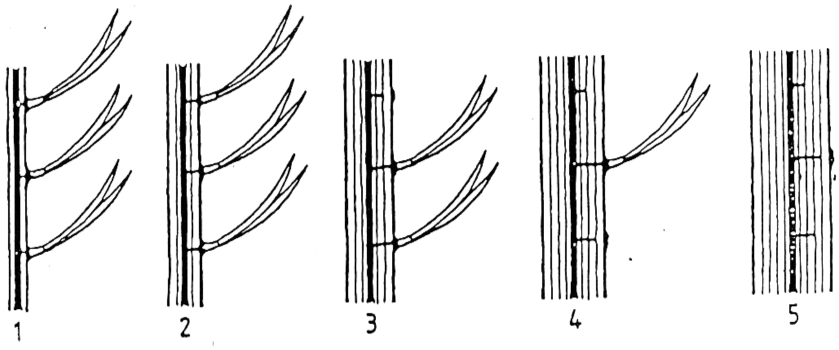

Figure 2. Pine shoots with attached needles and with the remains (needle traces) of fallen needles in wood in five years (Aalto and Jalkanen 1996).

Every annual section of tree have to be analysed, tree ring by tree ring, towards the pith to get the retrospective dataset of needle characteristics. An angle (usually from 45 to 90 degrees) has to be drawn on the both ends of the bolt, extending it from the pith outwards. Lines to connect the two angles have to be then drawn on the longitudinal surface of the eastern side. All needle traces within viewing plane have to be counted and the data have to be entered to the computing program NTMENG.

NTM has been already successfully used in retrospective studies of the growth losses of host trees, subsequent to the defoliation of pines by *Lophodermella* needle-cast disease and by insect *Diprion pini*, both in Finland (Jalkanen et al. 1994 and Kurkela et al. 2005, respectively), but, as well, to the defoliation of spruces by *Gilpinia hercyniae* in Wales (Williams et al. 2003) and of Scots pines by *Bupalus piniaria* in Scotland (Armour et. al. 2003). The first trial of retrospective analyses of *Lophodermium* needle cast in Estonia was undertaken some years ago (Drenkhan – Hanso 2003).

2.5 Data analysis

Different years from 1887 to 2003 were covered by different numbers of the model trees, analysed by NTM (*Table 1*, column 5). Only young age periods of tree life (from 5…7 to 22…25 years in stands 1. – 4., from ca 3 to 13 years in stand 5.) in *P. sylvestris* stands (*Figure 3*) and from 5…7 to 22…25 years in *P. contorta* stand were included into the computations. According to the NTM protocol the radial growth of sample trees was analysed on the breast height but in the youngest (5.) stand the radial growth was analysed on the stump height.

Although the older sample trees were analysed by NTM until the age of 35-45 years, the needle data, used in this investigation, were restricted by the younger period of tree life, not more than 25 years, because *Lophodermium* needle cast is not dangerous to older Scots pines. In this work recording of the needle trace data were used for calculating annual needle retention and, after that, the annual needle loss.

Annual needle retention (ANR), defined as the sum of the percentages of needles remaining on the leader sections of a tree in a particular year (Aalto and Jalkanen 1998; Pensa and Jalkanen 1999; Williams et al. 2003), was calculated using the equation:

$$ANR_t = \sum[x_t, (x\text{-}1)_t, \ldots, (x\text{-}n)_t]/100,$$

where ANR_t is the annual needle retention in year *t* (needle sets), x_t is the percentage of needles on leader section x present in year *t*, $(x\text{-}1)_t$ is the percentage of needles in year on the leader section formed on year earlier, etc.

Annual needle loss was calculated as:

$$ANL_t = (ANR_t - ANR_{t+1})+1,$$

where ANL_t is the total loss of needles (needle sets) in year *t*, and the term 1 represents the new flush of needles in year (t+1) (Aalto – Jalkanen 1998; Pensa – Jalkanen 1999).

The annual needle loss means the decrease in the amount of needle cohorts (defoliation) from the total main stem in a definite year, which is represented as the number of needle sets lost per year. The size of a needle set was calculated by evaluating a complete cohort of needles (i.e. a set of needles produced in a single year) with the value of 1 (100%), a needle cohort, where 75% needles had remained with the value of 0,75, and a needle cohort, where 50% of the needles had remained with the value of 0,5, etc. (Jalkanen 1998; Armour et. al. 2003).

NTM data were calculated by the special program NTMENG version 8 (Aalto – Jalkanen 2004). Statistical analyses were carried out by MS Excel and statistical program SAS.

3 RESULTS AND DISCUSSION

The development of *Lophodermium seditiosum* is very irregular and depends on environmental, particularly climatic factors (Martinsson 1979). The main source of *L. seditiosum* inoculum for infections in plantations is young infected fallen needles on which ascocarps of the fungus form in late summer and autumn (Diwani and Millar 1990). Wet and warm autumns provoke the epidemics in Estonia (Viirok 1931) as do the mild winters (Lepik 1930). Increased problems with *Lophodermium* needle cast in Sweden during the 1990s might be due in part to the occurrence of several consecutive mild winters (Stenström – Arvidsson 2001). Epidemiology of *Lophodermium* needle cast was first analysed by L. Lanier – G. Sylvestre (1971). A. van Maanen – F. Gourbière (2000) conducted an investigation into whether *Lophodermium pinastri* dynamics is determined by the balance between colonization and fructification. Both of these processes were found to be controlled by climatic factors, particularly rainfall. The conclusion was made, that spore production of the pathogen correlates with fructification, and colonization correlates with spore dispersal. It is the best short explanation, why the climatic factors determine the success of an epidemic.

In the earlier (first half of the XX century) literature *Lophodermium* needle cast has been mentioned in Estonia several times, sometimes presumably after the noticeable epidemics of the disease (Weiß 1902, Anonymous 1906 and 1907, S.-K. 1907, Krüger 1910, Aun 1922, Reim 1924 and 1925, Sepp 1928, Viirok 1931, Lepik 1930, Kohh 1933, Stegman 1936). During the Soviet occupation time (i.e. until the 1990s) *Lophodermium* needle cast has been investigated in Estonia in several works (Hanso 1963, 1968, 1970 and 1995, Hanso – Hanso 2001, 2003), but official registration of the data concerning the epidemics and economic losses in forest nurseries of the former (i.e. Soviet) Estonia has been always concealed and/or neglected. Therefore there is still a blank in our knowledge, although theoretical approaches by that time were solved sufficiently, if not even well, and the disease and its control peculiarities introduced to the practical foresters.

Table 1 represents the potential epidemic years of the disease, therefore the preceding years, supporting the rise of the epidemic through its meteorological peculiarities (two combinations of the summer months and following mild winters, cf. columns 1 and 3, respectively) are not indicated separately. If the NTM data in a potential epidemic year (i.e. after a year with high precipitation in summer and following mild winter) showed, as well, a "high needle loss" (i.e. higher than the mean needle loss of the years of all the period, covered by our NTM data), then the year was classified as an epidemic year for pine plantations (bold numbers in column 7 of the *Table 1*). Following solely the "high precipitation and mild winter" years (i.e. without high needle loss) were classified as potential epidemic years only for forest nurseries (indicated in the *Table 1* with "?" after the year number). Letters after the year numbers in column 7 indicate other important threshold years, concerning *Lophodermium* needle cast in Estonia (e.g. first records, published in German and Estonian, respectively, cited in literature epidemic years, etc., the piths of the letters are specified under the *Table 1*).

Table 1. The result table

High precipitation in VII-IX + mild winter	High precipitation in VII-IX + mild winter + high annual needle loss	High precipitation in VII-VIII + mild winter	High precipitation in VII-VIII + mild winter + high annual needle loss	The number of sample trees, which NTM data cover the appropriate year	High annual needle loss in *Pinus contorta*	Important threshold and epidemic years in history attributed to *Lophodermium seditiosum*
1	**2**	**3**	**4**	**5**	**6**	**7**
1884	1884	**1884**	1884		1884	1884 **?**
1885	1885	1885	1885		1885	1885
1886	1886	1886	1886		1886	1886
1887	1887	**1887**	1887	1	1887	1887 **?**
1888	1888	1888	1888	4	1888	1888
1889	1889	1889	1889	4	1889	1889
1890	1890	1890	1890	6	1890	1890
1891	1891	1891	1891	6	1891	1891
1892	1892	1892	1892	7	1892	1892
1893	1893	1893	1893	8	1893	1893
1894	**1894**	1894	1894	8	1894	**1894**
1895	1895	1895	1895	8	1895	1895
1896	**1896**	**1896**	**1896**	8	1896	**1896**
1897	1897	1897	1897	8	1897	1897
1898	1898	**1898**	1898	8	1898	1898 **?**
1899	1899	**1899**	1899	8	1899	1899 **?**
1900	1900	1900	1900	8	1900	1900
1901	1901	1901	1901	8	1901	1901
1902	1902	1902	1902	8	1902	1902[a]
1903	1903	**1903**	1903	8	1903	1903[b] **?**
1904	**1904**	**1904**	**1904**	8	1904	**1904**
1905	1905	**1905**	1905	4	1905	1905 **?**
1906	1906	**1906**	1906	4	1906	1906 **?**
1907	1907	1907	1907	7	1907	1907[c]

Table 1. cont. The result table

High precipitation in VII-IX + mild winter	High precipitation in VII-IX + mild winter + high annual needle loss	High precipitation in VII-VIII + mild winter	High precipitation in VII-VIII + mild winter + high annual needle loss	The number of sample trees, which NTM data cover the appropriate year	High annual needle loss in *Pinus contorta*	Important threshold and epidemic years in history attributed to *Lophodermium seditiosum*
1	**2**	**3**	**4**	**5**	**6**	**7**
1908	1908	1908	1908	8	1908	1908
1909	1909	1909	1909	8	1909	1909
1910	1910	**1910**	1910	8	1910	1910 **?**
1911	1911	**1911**	**1911**	8	1911	**1911**
1912	1912	1912	1912	8	1912	1912
1913	1913	1913	1913	8	1913	1913
1914	1914	1914	1914	8	1914	1914
1915	1915	1915	1915	8	1915	1915
1916	1916	1916	1916	8	1916	1916
1917	1917	1917	1917	8	1917	1917
1918	1918	**1918**	1918	8	1918	1918 **?**
1919	1919	1919	1919	7	1919	1919
1920	1920	1920	1920	7	1920	1920
1921	1921	1921	1921	7	1921	1921
1922	1922	1922	1922	5	1922	1922[d]
1923	1923	1923	1923	4	1923	1923[e]
1924	1924	1924	1924	2	1924	1924[f]
1925	1925	**1925**	1925	1	1925	1925 **?**
1926	1926	1926	1926		1926	1926
1927	1927	1927	1927		1927	1927
1928	1928	1928	1928		1928	1928
1929	1929	1929	1929		1929	1929[g]
1930	1930	**1930**	1930		1930	1930 **?**
1931	1931	1931	1931		1931	1931
1932	1932	1932	1932		1932	1932
1933	1933	1933	1933		1933	1933
1934	1934	**1934**	1934		1934	1934 **?**
1935	1935	**1935**	1935		1935	1935 **?**
1936	1936	**1936**	1936		**1936**	1936
1937	1937	**1937**	1937		1937	1937 **?**
1938	1938	**1938**	1938	5	**1938**	1938
1939	**1939**	**1939**	**1939**	7	1939	**1939**
1940	1940	1940	1940	8	1940	1940
1941	1941	1941	1941	8	1941	1941
1942	1942	1942	1942	8	1942	1942
1943	**1943**	**1943**	**1943**	8	1943	**1943**
1944	**1944**	**1944**	**1944**	8	**1944**	1944
1945	1945	1945	1945	8	1945	1945
1946	1946	1946	1946	8	1946	1946
1947	1947	1947	1947	8	1947	1947
1948	1948	1948	1948	8	1948	1948

Table 1. cont. The result table

High precipitation in VII-IX + mild winter	High precipitation in VII-IX + mild winter + high annual needle loss	High precipitation in VII-VIII + mild winter	High precipitation in VII-VIII + mild winter + high annual needle loss	The number of sample trees, which NTM data cover the appropriate year	High annual needle loss in *Pinus contorta*	Important threshold and epidemic years in history attributed to *Lophodermium seditiosum*
1	**2**	**3**	**4**	**5**	**6**	**7**
1949	**1949**	**1949**	**1949**	8	1949	**1949**
1950	1950	1950	1950	8	1950	1950
1951	1951	1951	1951	8	1951	1951
1952	1952	1952	1952	8	1952	1952
1953	1953	1953	1953	8	1953	1953
1954	1954	1954	1954	8	1954	1954
1955	**1955**	**1955**	**1955**	8	1955	**1955**
1956	1956	1956	1956	6	1956	1956
1957	1957	**1957**	**1957**	1	1957	**1957**
1958	1958	1958	1958	2	1958	1958
1959	1959	1959	1959	2	1959	1959
1960	1960	1960	1960	2	1960	1960
1961	1961	**1961**	**1961**	2	**1961**	**1961**[h]
1962	1962	**1962**	1962	2	1962	1962 ?
1963	1963	1963	1963	2	1963	1963
1964	1964	1964	1964	3	1964	1964
1965	1965	1965	1965	3	1965	1965
1966	1966	1966	1966	3	1966	1966
1967	1967	1967	1967	3	1967	1967
1968	1968	1968	1968	3	1968	1968
1969	1969	1969	1969	3	1969	1969
1970	1970	1970	1970	3	1970	1970
1971	1971	1971	1971	3	1971	1971
1972	1972	1972	1972	3	1972	1972
1973	1973	1973	1973	3	1973	1973
1974	**1974**	**1974**	**1974**	3	1974	**1974**
1975	1975	1975	1975	3	1975	1975[i]
1976	1976	1976	1976	3	1976	1976
1977	1977	1977	1977	1	1977	1977
1978	1978	1978	1978	1	1978	1978
1979	1979	1979	1979	1	1979	1979[j]
1980	1980	1980	1980	1	1980	1980
1981	1981	1981	1981		1981	1981
1982	1982	1982	1982		1982	1982[k]
1983	1983	1983	1983		1983	1983
1984	1984	1984	1984		1984	1984
1985	1985	1985	1985		1985	1985
1986	1986	1986	1986		1986	1986
1987	1987	1987	1987		1987	1987
1988	1988	**1988**	1988		1988	1988 **?**
1989	1989	**1989**	1989		1989	1989 **?**

Table 1. cont. The result table

High precipitation in VII-IX + mild winter	High precipitation in VII-IX + mild winter + high annual needle loss	High precipitation in VII-VIII + mild winter	High precipitation in VII-VIII + mild winter + high annual needle loss	The number of sample trees, which NTM data cover the appropriate year	High annual needle loss in *Pinus contorta*	Important threshold and epidemic years in history attributed to *Lophodermium seditiosum*
1	**2**	**3**	**4**	**5**	**6**	**7**
1990	1990	1990	1990		1990	1990
1991	1991	**1991**	1991		1991	1991**?**
1992	1992	1992	1992		1992	1992
1993	1993	1993	1993		1993	1993
1994	1994	**1994**	1994		1994	1994 **?**
1995	1995	1995	1995	1	1995	1995 **?**
1996	1996	1996	1996	3	1996	1996
1997	1997	1997	1997	9	1997	1997
1998	1998	1998	1998	37	1998	1998
1999	**1999**	**1999**	**1999**	62	1999	**1999**[l]
2000	2000	2000	2000	68	2000	2000
2001	**2001**	**2001**	**2001**	67	2001	**2001**[m]
2002	2002	2002	2002	67	2002	2002
2003	2003	2003	2003	66	2003	2003
2004	2004	**2004**	2004		2004	2004[n]

Legend: The gray field covers the years, for which the NTM data are still missing.
The bold numbers in column 7 indicate the epidemic years in forest plantations.
The bold numbers and normal black numbers in column 7 indicate the possible epidemic years in forest nurseries.
The bold numbers in column 6 indicate the years with high needle loss in the *Pinus contorta* stand.

a – the first published information about Lophodermium needle cast in Estonia (in German),
b – the first published record of the agent fungus in Estonia,
c – the first published in Estonia instructions for the control of the disease,
d – the first published information about Lophodermium needle cast in Estonia (in Estonian),
e – **k** - documented epidemics of Lophodermium needle cast in Estonia.

Our experimental material (NTM data concerning the dynamics of needle loss in pines) is presented on *Figure 3*. According to our computations, including and considering, as well, the literature and other data, the definite Lophodermium needle cast epidemic years in Estonia were: 1) in young pine plantations: 1894, 1896 (the both before the first records of the disease and its agent in literature!), 1904, 1911, 1939, 1943, 1949, 1955, 1957, 1961, 1974, 1999 and 2001; and 2) in forest nurseries: 1884, 1887, 1894, 1896, 1898, 1899, 1903, 1904, 1905, 1906, 1910, 1911, 1918, 1925, 1930, 1934, 1935, 1937, 1939, 1943, 1949, 1955, 1957, 1961, 1962, 1974, 1988, 1989, 1991, 1994, 1995, 1999, 2001 and 2004.

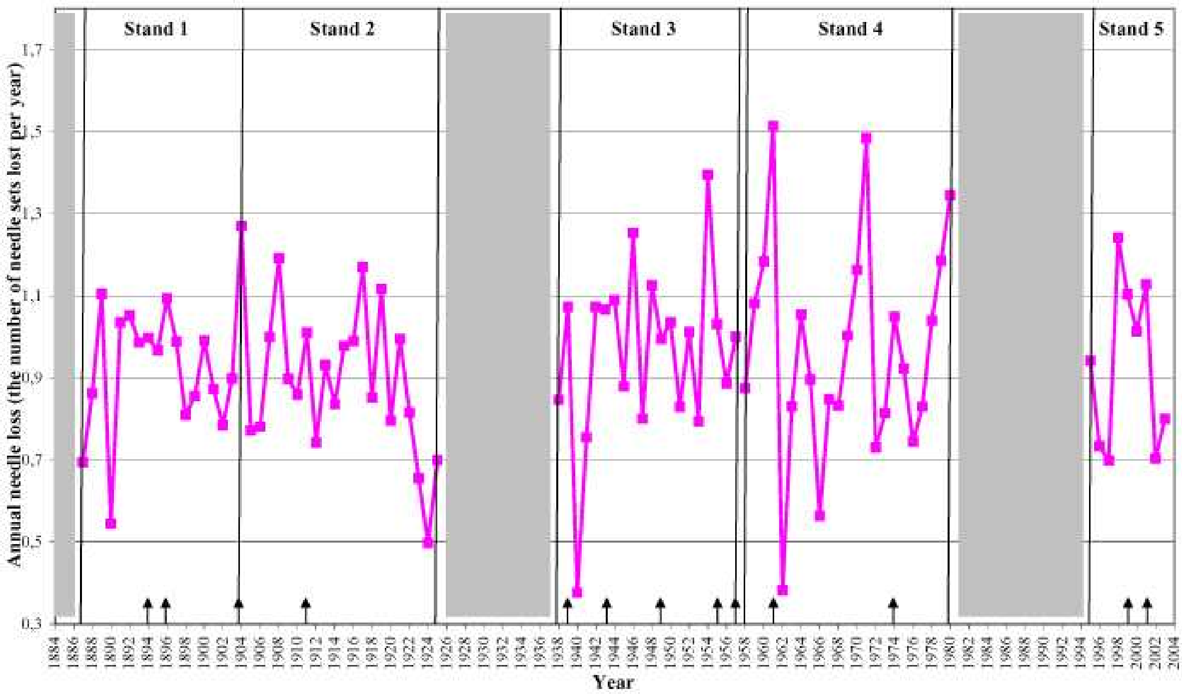

Figure 3. Annual needle loss dynamics during the young age (<25 years) of the analysed by NTM five Scots pine stands in South-East Estonia. Arrows below indicate the possible Lophodermium needle cast epidemic years (on the base of meteorological + NTM data). Grey fields cover the years, for which the NTM data are still missing.

Inside the long period (1884-2004) the documented in the literature (or by the services in forest pathology) epidemic years of Lophodermium needle cast in Estonia were 1923, 1924, 1929, 1961, 1975, 1979, 1982, 1999, 2001 and 2004 (*Table 1*). The years of high annual needle loss coincided with the documented epidemic years in 1961, 1979, 1999 and 2001 (*Figure 3*), which mean values (1,233 +/- 0,1) were higher than the long period (1887-2003) mean annual needle loss (0,966 +/- 0,013). Regarding the meteorological characteristics, the years 1961, 1999, 2001 and 2004 were selected out namely as the years, characterized by the combinations of high precipitation summer (VII-IX or VII-VIII) of the preceding year and following mild winter. At the same time the years 1923, 1924, 1929, 1975, 1979 and 1982, although documented in the literature as epidemic years, were not characterized by the supporting the pathogen preceding conditions (wet summers + mild winters). The years 1923, 1924 and 1975 (but not 1979) had low annual needle loss values compared to the long period mean. The reasons of these low values would be: a) trees in the appropriate age were not any more seriously affected by the Lophodermium needle cast, b) the amount of sample trees, covering the appropriate years were not sufficiently represented in the NTM material (at least 5 trees per year have to be analyzed, but e.g. the year 1979 was represented by only a single sample tree, although with high needle loss) and c) the weather data combinations were not perfectly selected for opening the potential epidemic years, in other words: we still do not know the actual needs of the pathogen. For the years 1929, 1982 and 2004 the NTM data are missing (*Table 1*).

Comparison of the appropriate meteorological data of documented Lophodermium needle cast epidemic years with the long period (1884-2004) means showed us, that: 1) the both combinations of summers of epidemic years had the mean precipitation values close to the long period mean (except of 1975), and 2) the mean winter temperatures had even lower values than long period mean in the epidemic years 1923, 1924, 1929, 1979 and 1982 (*Table 2*).

The low winter temperature, therefore, seems not to be a serious problem for the pathogen in raising a new epidemic, and if the level of summer precipitation is close to the long period mean, the epidemic can get start.

Table 2. Mean meteorological characteristics (summer precipitation and winter temperature) of the years preceding to the documented Lophodermium needle cast epidemic years

Year	Precipitation sum during VII-IX (mm)	Precipitation sum during VII-VIII (mm)	Monthly XII-III temperature (°C)
1923	216,0	189,0	-5,4
1924	270,0	185,0	-6,6
1929	329,0	217,0	-7,9
1961	186,0	157,0	-0,1
1975	190,0	145,0	-0,7
1979	381,0	272,0	-8,4
1982	247,0	181,0	-5,2
1999	292,0	268,0	-3,6
2001	237,0	225,0	-2,2
2004	201,5	187,2	-3,1
Long period (1884-2004) mean	220,1+/-6,6	157,9+/-5,5	-4,9+/-0,2

Our NTM material concerning *Pinus contorta* (stand 6) betrayed high annual needle loss values of this pine species in the years 1936, 1938, 1944 and 1961 (*Table 1*, column 6). These losses were caused, seemingly, by the other agents (perhaps by the starting epidemic of *Gremmeniella abietina*, which was first documented in Estonia in 1964, cf. Hanso, 1969, 1972). *P. contorta* is considered to be resistant to Lophodermium needle cast. However, our hopes to find clear differences in the dynamics of needle losses in these pine species (*P. sylvestris* and *P. contorta*) failed, as during some of the presumably epidemic years of Lophodermium needle cast (e.g. 1961) both the pine species had high needle loss. During the years of diagnostic service in the forest nursery management system of Estonia (1972-1985) we had diagnosed (by personal communication of the elder author) serious Lophodermium needle cast attack on *Pinus contorta* seedlings twice, in 1978 and 1979.

We can set aside the possibility, that any insect defoliator could cause the extensive needle loss of pines during the study years, as it is generally known, that insect pests accompany namely hot and dry, and not wet summers as do fungal diseases. However, we decided to look for the appropriate (i.e. hot and dry) summers and see, which kind of needle losses were following these, presumably congenial to insects, years. It was found, that all the years with hot summers were followed by the years with annual needle loss, less than the long period mean. Therefore we can believe, that none of our five Scots pine stands had lost considerable amount of needles in their youth through the insect attack.

Large scale epidemics of Coleosporium needle rust – another possible interfering our conclusions fungal disease of pine needles - are seldom in Estonia. Although the fungus (fungi) can be found year by year, they are few in numbers (personal communication by the elder author). Epidemics of *Hypodermella sulcigena* or *H. conjuncta* are rear, as well, in Estonia.

4 CONCLUSIONS

As the bases of the modern disease regulation (control) system in growing pine seedlings in forest nurseries can be, only and strictly, prophylactic, the prognoses must lie in the foundation of an appropriate system. A retrospective list of epidemics from the history will hopefully improve the raising of a more acceptable prognostic system than it exists today.

According to our computations by the use of NTM (needle trace method), including and considering, as well, the literature and other data, the definite Lophodermium needle cast epidemic years in Estonia were:
1) in young pine plantations: 1894, 1896 (the both before the first records of the disease and its agent in literature!), 1904, 1911, 1939, 1943, 1949, 1955, 1957, 1961, 1974, 1999 and 2001; and 2) in forest nurseries: 1884, 1887, 1894, 1896, 1898, 1899, 1903, 1904, 1905, 1906, 1910, 1911, 1918, 1925, 1930, 1934, 1935, 1937, 1939, 1943, 1949, 1955, 1957, 1961, 1962, 1974, 1988, 1989, 1991, 1994, 1995, 1999, 2001 and 2004.

The appropriate analyses, represented in this investigation, is not ended as there are some large periods which are not covered at all or are covered by insufficient amount of the NTM material.

Hopefully, the NTM will serve us in the future as well in the investigations, which have to elucidate the role of Lophodermium needle cast epidemics in the selection of surviving and failing trees during the rich-in-victims formation of a pine stand. As well the question: how large territory is occupied by a Lophodermium needle cast epidemic, is still not answered.

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