INFLUENCE OF DROUGHTS TO THE RADIAL GROWTH OF SCOTS PINE (*Pinus sylvestris* L.)

ADOMAS VITAS, REGINA ERLICKYTĖ

Vytautas Magnus University Faculty of Nature Sciences Environmental Research Centre Group of Dendroclimatology and Radiometrics, Ž.E. Žilibero 2, LT-46324 Kaunas, Lithuania; e-mail: a.vitas@gmf.vdu.lt
Lithuanian Energy Institute Laboratory of Renewable Energy, Breslaujos 3, LT-44403 Kaunas, Lithuania; e-mail: regerl@mail.lei.lt

Abstract

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Dendroclimatological research on the radial growth of Scots pine in Lithuania has been conducted. The aim of the study was to estimate the differences of the impact of droughts on dry and wet growing sites. Impact of droughts on the radial growth of pine using pointer years (i.e. years with narrow tree rings in the majority of trees) was investigated. Research has revealed that winter colds and summer droughts are attributed as causes of negative pointer years. Totally, six pointer years of pines radial growth have been provoked by droughts during 20th century. Pines growing on wet boggy sites (*Myrtillo-spaghno-Pinetum*) have been established to be sensitive to dry climate conditions in summer. It was established that the number of pines affected by droughts on wet sites is even bigger than on dry sites.

Key words: dendroclimatology, droughts, event year, pointer year, Scots pine, soil water, tree rings

Introduction

Scots pine (*Pinus sylvestris* L.) has been one of the most comprehensively investigated tree species in Lithuania and Baltic countries by using dendroclimatological techniques. This was determined by the prevalence of pines in forests of Lithuania (about 36.2% of the total stands), pine longevity and wide ecological amplitude of its growing sites. Tree rings of pine have been in the focus from the first dendrochronological research in Lithuania (Bitvinskas, 1974). Tree rings of Scots pine were also successfully applied for the long-term millennial chronologies used in climate reconstruction (Grudd et al., 2002; Helama et al., 2002; Pukienė, 1997).

The main attention during the previous dendroclimatological research was devoted to the influence of winter temperatures to the tree rings of Scots pine (Bitvinskas, 1974) and winter colds were confirmed as the main factor limiting radial growth (Yadav et al., 1991). Later studies have observed impact of precipitation in spring and summer, which, however, is less important than of air temperatures in winter (Karpavičius et al., 1996; Vitas, 2004a; Vitas, Bitvinskas, 1998).

Dendroclimatological investigation on pine tree rings in Latvia (Špalte, 1978), Estonia (Läänelaid, 1982), Poland (Cedro, 2001), and Scandinavia (Linderson, 1992) provided similar results that pine is the most sensitive to cold winters. However, it was established that rainfall during summer in Poland induces wide rings of pine (Cedro, 2001).

Due to high tolerance of Scots pine to different and variable soil moisture conditions (Polacek et al., 2006), previous research has involved wide range of site conditions (from peat bogs to infertile and dry mineral sites). Dendroclimatological knowledge states that drought sensitive trees grow on dry mineral soils and suffer from lower amounts of precipitation (Fritts, 1987). Many studies have proven that pines on peat bogs respond to precipitation negatively, especially during summer time (Bitvinskas, 1974; Boggie, 1972; Jasnowska, 1977; Läänelaid, 1982), but several studies have admitted contradictory results affirming positive, usually insignificant, impact of precipitation on pine radial growth at wet sites (Karpavičius, 1993; Linderholm, 2001). This may be related to a shallow root system of sites with a high water table (Lieffers, Rothwell, 1986). Trees may become fewer droughts tolerant after the decrease of water level (Kozlowski, 1997).

It is evident that the changes in several climatic parameters at the end of 20th century in Lithuania (Bukantis, 1998; Bukantis et al., 2001) lead to the decreased influence of winter colds along with the increased importance of droughts during spring and summer (Vitas, Žeimavičius 2006; Vitas, 2004b). More frequent droughts are possible consequences of the global climate change (Bukantis et al., 2001; Breshears et al., 2005; Hoerling, Kumar, 2003).

Our study is aimed to qualify the differences of the impact of droughts to Scots pine radial growth on dry and wet sites and to provide better understanding of the influence of precipitation to pines growing on sites with a high water table.

Material and methods

The territory of Lithuania is located between maritime and continental climate zones of middle latitude. Research plots are located in Aukštaitija National Park (northeastern Lithuania). Northeastern Lithuania is characterized by the most continental climate conditions – the shortest period of vegetation (185 192 days) and coldest winters (-5.0 to -6.8 °C) in comparison to the other regions of Lithuania. Territory of a National Park was strongly affected by the last glacial withdrawal, which left the rugged terrain. Smaller or bigger lakes and peat bogs are formed usually on the lowest sites of it.

The terrain, where research plots were selected, is located between two small lakes – Žiegžmaris and Ešerinis in Ažvinčiai Forest (Fig. 1). For the purpose of research, eight experimental plots of Scots pine were selected (Table 1). Six research plots are located in peat bog with thinner or thicker organic soil layer and two of them – on the periphery of the peat bog with mineral soil and deeper ground water level (up to 226 cm). The terrain is located 180 m a.s.l.

Fig. 1. Location of research area in Lithuania scale.

T a b l e 1. Characteristics of research plots (soil and forest type, geographical coordinates) and sampled trees (number of cored trees, DBH).

Name	Soil type	Forest type	Geographical coordinates		Number of trees	DBH, cm
			Latitude (N)	Longitude (E)		
es1-2	Organic	*Myrtillo-spaghno-Pinetum*	55°25’53”	26°02’38”	10	40
es3-4	Organic	*Myrtillo-spaghno-Pinetum*	55°25’60”	26°02’38”	10	37
es5	Mineral	*Vaccinio-myrtillo-Pinetum*	55°25’64”	26°02’34”	10	42
es6	Organic	*Myrtillo-spaghno-Pinetum*	55°25’63”	26°02’39”	6	32
es7	Organic	*Myrtillo-spaghno-Pinetum*	55°25’67”	26°02’34”	10	27
es8	Organic	*Ledo-sphagno-Pinetum*	55°25’70”	26°02’33”	9	18
es9	Mineral	*Myrtillo-Pinetum*	55°25’71”	26°02’39”	10	42
es10–12	Organic	*Myrtillo-spaghno-Pinetum*	55°25’82”	26°02’28”	8	27

Several soil parameters have been investigated in the research area. The measurements of a soil water level in research plots were launched in 1997. This is done every ten day from spring to autumn (approximately from mid April to beginning of November) in the special soil holes. The acidity of soil water was measured using pH-meter within 0.1 pH value accuracy.

Using increment borer, cores from six to ten trees of co-dominant, dominant and emergent crown classes in each plot at the breast height were taken. Four cores were taken from each tree. The mean DBH of selected trees varies from 18 cm to 42 cm (Table 1).

Tree ring widths with preciseness of 0.001 mm were measured. For this purpose, LINTAB tree-ring measuring table and WinTSAP 0.30 computer program (F. Rinn Engineering Office and Distribution, Heidelberg) were used.

The measured series were cross-dated by visual comparison (Eckstein, 1987) of ring-width graphs and checked statistically using COFECHA 3.00P computer program (R.L. Holmes, Tucson) (Holmes, 1994). Four tree-ring width radii were averaged into a series of individual trees and checked again for dating errors.

Standardisation of the series was carried out using CHRONOL 6.00P program (R.L. Holmes, Tucson). Each tree ring width series belonging to individual tree was indexed separately.

The long-term regression analysis seldom permits to evaluate effect of extreme climate conditions (information contained in conspicuous single growth rings). For this purpose event and pointer year analysis by using method "normalisation in a moving window" proposed by H.F. Schweingruber was performed (Schweingruber, 1990, 1993; Schweingruber et al., 1990). Calculations were accomplished by using WEISER 1.0 computer program (I.G. Gonzales, Lugo) (Gonzales, 2001). Index value for event year (i.e. year with extremely narrow or wide tree ring) is calculated by Formula 1:

$$Z_i = \frac{x_i - mean[window]}{stdev[window]}, \quad (1)$$

where: Z_i – index value in year i; x_i – original value (mm) in year i; $mean[window]$ – arithmetic mean (mm) of the ring width within window $x_{i-2}, x_{i-1}, x_i, x_{i+1}, x_{i+2}$; $stdev[window]$ – standard deviation of the ring width within window $x_{i-2}, x_{i-1}, x_i, x_{i+1}, x_{i+2}$.

The threshold value of Z_i for negative event years is ≤ -0.75. Pointer years during 1813–2005 were detected using a 75% threshold level of event years.

Measurements of air temperature and precipitation in the region of Aukštaitija National Park are available only from the beginning of 20th century. Therefore, climatologically interpretation of pointer years during the 19th century is uncertain, because for this century only data of air temperature from Vilnius Meteorological Station (about 100 km distance) are available.

For the climatological interpretation of detected pointer years, climate extremes according to Utena Meteorological Station were estimated. According to the common climatological practice (Bukantis, 1998), climate extremes are judged if the differences of air temperatures or precipitation from the long term mean exceed the standard deviation. For the estimation of droughts in spring and summer, a slightly modified method (Formula 2) proposed by Walter (1974) was used.

$P_i \leq T_i$	Extreme drought	(2)
$T_i < P_i \leq 2T_i$	Drought	
$2T_i < P_i \leq 3T_i$	Arid conditions	

where: P_i – amount of precipitation (mm) during the month; T_i – average temperature (°C) during the analysed month.

Results

Dating among four radii of a tree and between trees was very complicated but successful and as a result eight pine chronologies were compiled (Fig. 2). The number of discovered wedging and missing rings is variable between the research plots (Table 2). The lowest

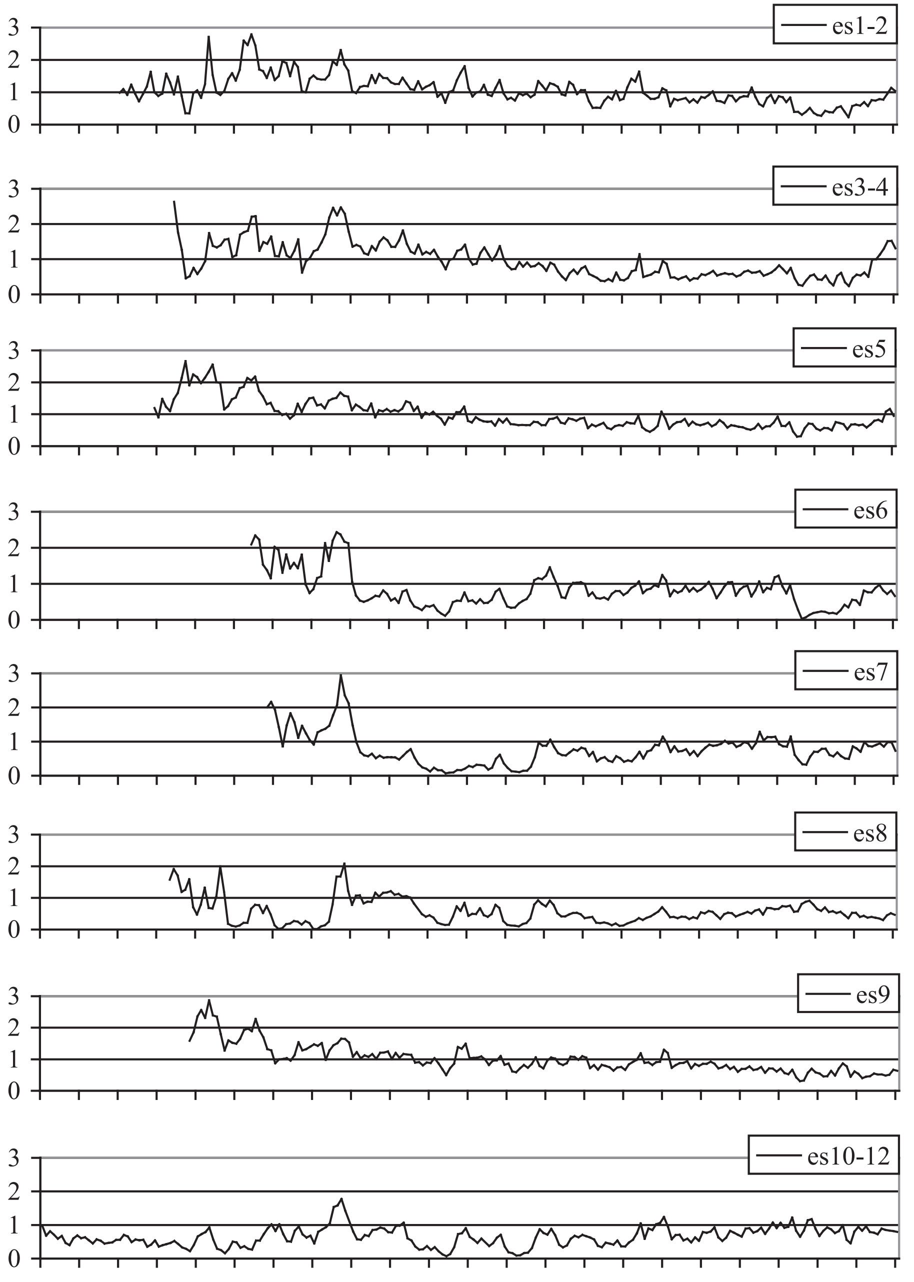

Fig. 2. Eight chronologies (es1-2 – es10-12, in mm) of Scots pine growing under different site conditions.

T a b l e 2. Statistical characteristics of plots and compiled chronologies: soil water level during the vegetation periods of 1997–2005 (cm), soil acidity (pH values), number of missing rings (%), average tree-ring width and length of compiled chronology.

Plot	Soil water level cm			pH value	Missing rings %	Tree ring width mm	Length of chronol-ogy years
	lowest	average	highest				
es1–2	76	32	4	3.42	0.59	1.09	201
es3–4	70	36	3	3.35	0.13	0.95	187
es5	247	226	201	6.05	0.06	0.98	192
es6	61	37	12	3.45	1.59	0.81	167
es7	80	51	21	3.30	0.48	0.73	163
es8	66	33	12	3.30	0.62	0.54	188
es9	89	72	51	4.35	0.00	0.99	183
es10–12	78	30	7	3.15	0.43	0.70	221

chance of wedging and missing rings is among pines growing on dry sites, characterized by mineral soil. The average soil water level during the vegetation period depends on soil features (Table 2). The average soil water level among sites with organic soil (forest type *Myrtillo-spaghno-Pinetum*) is 30–50 cm from the surface. The soil water rises up to 3–21 cm on sites with organic soil in spring or after more intensive and longer lasting rains. The average soil water level on mineral soils (*Myrtillo-Pinetum*) is deeper (72 cm) and never raises 51 cm below surface. The deepest soil water level (deeper than 2 m) is common for the driest *Vaccinio-myrtillo-Pinetum* forest type.

The water on organic (peat) soil is highly acid (3.15–3.45 pH). The acidity of mineral soils (*Myrtillo-Pinetum*) was established to be 4.35 pH and for *Vaccinio-myrtillo-Pinetum* – 6.05 pH (Table 2). The water of Lake Žiegžmaris located in the periphery of peat bog is around neutral (7.35 pH), while the water of small Lake Ešerinis, located in the middle of peat bog is highly acid (3.55 pH).

The average tree-ring widths are around or bellow 1 mm. The smallest radial growth was determined for es8 experimental plot, which also is characterized by smallest diameter of pines (Table 2). This is connected not only to predominating unfavourable growing conditions in highly acid environment and high water table but also to over-mature trees, which age reach 221 years (Table 2).

Relationships between the average depth of soil water and the radial growth of pines during April-September of 1997–2005 are presented in Table 3. Statistically significant coefficients of correlation are higher than ± 0.71 ($p < 0.05$). It is evident that there are only two statistically significant coefficients. The most stable and positive links have been discovered between soil water depth and the growth of pines in sites with mineral soil (es5 and es9) (Table 3). Increased soil humidity of mineral sites affects the radial growth of pines negatively and the increase of growth is favoured by the abatement of the soil water depth.

T a b l e 3. Coefficients of correlation between the average depth of soil water and the radial growth of pines at eight research plots during April–September of 1997–2005.

Months	es1–2	es3–4	es5	es6	es7	es8	es9	es10–12
Apr–May	-0.25	0.13	0.79	0.38	0.00	0.16	0.32	-0.11
Jun	-0.27	0.43	0.64	0.40	0.06	-0.13	0.42	-0.42
July	-0.22	0.03	0.43	0.26	-0.27	-0.39	0.17	-0.20
Aug	0.00	0.16	0.55	0.46	0.58	-0.33	0.33	0.31
Sep	-0.20	-0.05	0.55	0.49	-0.43	-0.53	0.27	0.25

The high soil water stimulates radial growth of pines on the wet sites (es1–2, es7, es8 and es10–12), which are located near lakes.

Negative pointer years of pine radial growth from 1900 to 2005 in eight research plots are presented in Table 4. Analysis of negative pointer years has shown that two main extremes (winter colds and summer droughts) are attributed as causes of pointer years. However, if both climate extremes (colds and droughts) occurred in the sane year, it is impossible to ascertain strictly the cause of pointer year. Totally, six pointer years (1907, 1914, 1920, 1935, 1971, and 1993) have been induced only by droughts on sites with mineral soil (es5, es9) and four pointer years (1920, 1935, 1978, 1993) – on sites with organic soil. Four pointer years have been established on both dry and wet sites, and they were caused exclusively by droughts (Table 4).

The average number of trees showing event year (distinct decrease of tree-ring width) in 1920, 1935, 1971, and 1993 is presented in Fig. 3. It is evident that the amount of trees showing event year usually is between 60 and 80% and only in 1993 has exceeded 80%. The average percentage of trees with event years on mineral and organic soils is similar.

Discussion

In spite of that living mature and over-mature trees are the most valuable sources for dendrochronological investigations, providing as long as possible tree-ring width series, dating of such trees often is difficult, especially if they growth in unfavourable environment. Pine growth in peat bogs is characterized by small size of stems and narrow rings, which often transits into wedging rings on different sides of the stem. During periods with unfavourable growth in peat bogs missing rings are detected occasionally. Precise dating of measured tree-ring series was successful mainly because of four taken cores per tree and tree ring widths series were constructed.

The frequency of wedging and missing rings is directly connected not only to the age of trees, but also depend on growing conditions of pines (Table 2). The least frequency of missing rings was established among pines growing on mineral soils, which are character-

T a b l e 4. Pointer years (1900–2005) in the radial growth of Scots pine in eight research plots. Values indicate percentage of trees with event years. Air temperature extremes in winter and spring (January–April) are shown as deviation (°C) from the long-term mean. Droughts during May–August are expressed with abbreviations: extreme drought (ED), drought (D), arid conditions (A). Empty cells indicate that climate conditions in these years were around the long-term mean.

Year	Research plots								Climate conditions							
	es 1-2	es 3-4	es 5	es 6	es 7	es 8	es 9	es 10-12	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1900					-90			-88				-2.6	D	A	A	A
1901	-89	-80											A		ED	
1907							-90	-88					A	A		
1914							-90			4.7					A	ED
1915		-80									-4.6		A	ED	A	D
1919				-83				-88				5.3	D			
1920	-80	-80	-80	-100							3.0	5.5			A	
1923		-80				78						-2.2			A	
1925						-89			5.1	4.9			A			
1935	-80	-80					-80	-75								A
1940		-80		-100	-80	-78		-75	-9.9	-8.8	-4.6	-2.1		D		
1942			-90						-10.3	-6.8	-9.0	-2.3				D
1947	-100	-80	-90	-100			-100			-8.3			D			
1954					-100	-78			-4.8	-7.2		-2.7	A			
1959				-100							3.2				A	
1964	-100			-100		-89		-75			-4.2		A	A	D	
1970	-100									-4.5			A	ED	A	A
1971	-90					-100	-80	-88						A	A	D
1979						-78								ED		
1980			-90			-89	-100	-100			-3.7			A		
1981	-100	-90	-80	-100	-90		-80					-2.3			A	
1988				-83									A			
1992					-90				4.5	4.2	3.9			ED	D	A
1993	-80	-88	-90	-83		-100	-100	-100	4.1				D			
2002					-80	-89				6.8	4.0		D		D	D

ized by thickest stems and the biggest among pines in organic – peaty soils (Table 2). The negative relationships between the frequency of missing rings, soil water acidity and the average depth of soil water also exist, but coefficients are not significant statistically.

Because pine is very ecologically plastic species growing in almost all sites (Polacek et al., 2006), presented results varies not only geographically but also depend on site condi-

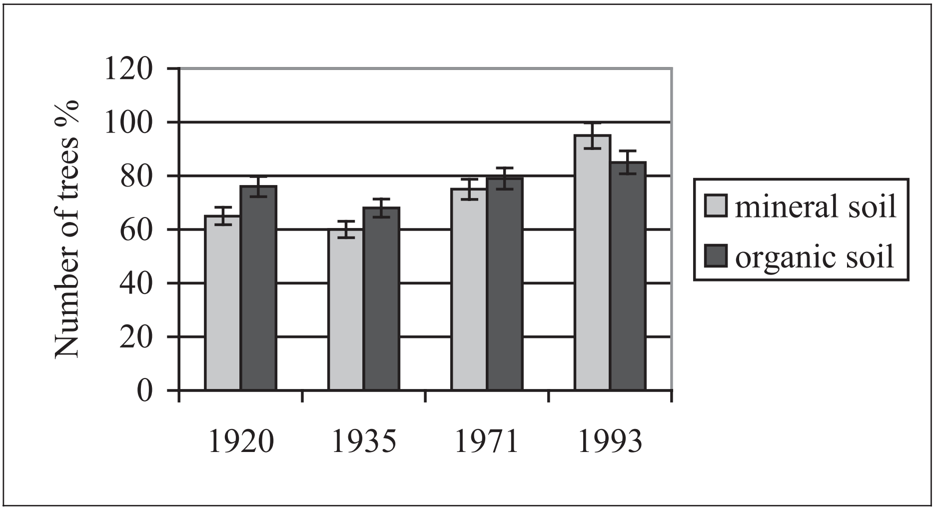

Fig. 3. Number of trees (%) showing negative events (decrease of the radial growth) on mineral and organic soils during pointer years induced by droughts (1920, 1935, 1971 and 1993).

tions. Dendroclimatological research on Scots pine in Lithuania has demonstrated that tree rings of pine are sensitive indicators of colds during winter and spring (Bitvinskas, 1974; Vitas, Bitvinskas, 1998; Yadav et al., 1991). Later research has proven this feature, but herewith hypothesized that there is effect of droughts during summer to the tree rings of pine (Karpavičius et al., 1996; Vitas, 2004a). Different results partly are connected to the long-term climate fluctuations: a period of cold winters (until 1986) and repeating summer droughts during the last decade of 20th century, which are possibly provoked by global climate change (Hoerling, Kumar, 2003; Hopkin, 2004). Dendroclimatological investigations on pine tree rings carried out in neighbouring countries provided similar results that pine is the most sensitive to cold winters (Läänelaid, 1982; Špalte, 1978), while precipitation has a secondary importance (Cedro, 2001; Linderson, 1992).

A surplus of soil humidity common to peat bogs forms unfavourable growing conditions by altering variety of physical, chemical and biological processes (Kozlowski, 1997). These include shortage of oxygen, accumulation of CO_2, increased solubility of mineral substances, reduction of Fe and Mn, anaerobic decomposition and formation of toxic compounds (Ponnamperuma, 1984; Gambrell et al., 1991). Physiologically tree responds to drought through stomatal closure – improving water use (Croker et al., 1998). Stomatal closure reduces rate of photosynthesis (Percival, Sheriffs, 2002). The most important feature of drought resistant plants is dehydration tolerance (Ludlow, 1989).

Earlier investigations concluded that trees growing on peatlands are highly dependent on depth and fluctuations of the water table (Boggie, 1972; Bitvinskas, 1974; Jasnowska, 1977; Läänelaid, 1982). It depth is controlled by precipitation and temperature (Mannerkorski, 1991). However, J. Karpavičius (Karpavičius, 1993) discovered positive impact of precipitation in July on tree rings of pine growing in Žuvintas Reserve peat bog. This positive influence is probably due to shallow spreading root systems by sites with high water tables (Lieffers, Rothwell, 1986). Therefore, after the decrease of water level plants may become fewer droughts tolerant because of weaken absorption of water by small roots (Kozlowski, 1997).

Positive links between the soil water depth and the radial growth of pines (Table 3) on mineral sites (es5 and es9) confirm that pines are resistant to the decrease of soil water level in comparison to pines on organic soils, where negative links predominate. The most sensitive trees to the desiccation of soil grow in the wettest research plots (es1 2, es7, es8 and es10–12).

Research has shown that extreme climate conditions are often interconnected: winter colds often are followed by droughts. Therefore, interpretation of such pointer years is complicated. Totally, six pointer years on dry sites and four on wet sites have been attributed exclusively to droughts during 20th century. The most important pointer year provoked by drought during 20th century is 1993 (Table 4, Fig. 3). This pointer year was provoked not only by spring drought of 1993 but also by extreme droughts of 1992 (Bukantis, 1993; Vitas, 2001). Pines growing on dry and on wet sites have negatively responded to droughts (Table 4). Number of trees with event years growing on wet sites is even bigger than on dry sites (Fig. 3). This indicates that the response of the radial growth pines to droughts is not connected to the depth of soil water and other site characteristics.

Conclusion

1. Dendroclimatological research has revealed that winter colds and summer droughts are attributed as causes of negative pointer years of Scots pine radial growth.
2. Totally, six negative pointer years of radial growth have been provoked by droughts during 20th century.
3. Pines growing on wet boggy sites (*Myrtillo-spaghno-Pinetum*) have been established to be sensitive to dry climate conditions in summer. The number of trees affected by droughts on wet sites is even bigger than on dry sites.

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