Influence of Droughts to the Radial Growth of Scots Pine (*Pinus sylvestris* L.) in Different Site Conditions

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Vitas, A. and Erlickytė, R. 2007. Influence of Droughts to the Radial Growth of Scots Pine (*Pinus sylvestris* L.) at Different Site Conditions. *Baltic Forestry*, 13 (1): 10–16.

Abstract

Dendroclimatological research on the radial growth of Scots pine in the Aukštaitija National Park in north-eastern Lithuania has been conducted. The aim of the study was to estimate the differences of the impact of droughts on the radial growth of pines growing on dry and wet sites. For this purpose event years of the radial growth were estimated. The investigation has revealed that the fluctuations of the soil water level have different impact on the radial growth of pines. An increase in the soil water level stimulates the radial growth on sites with organic soil, but on sites with mineral soil the growth is positively affected by the abatement of the water level. We found that droughts in spring and early summer (May-June) are much more dangerous for the radial growth of pines, as compared to August. Droughts of three-month duration have been acknowledged to be more stressful than short one-month droughts. The effect of drought to the radial growth of pines depends on climate conditions before and after the drought. The investigation did not reveal significant differences between the number of pines with negative event years growing on sites in organic peat and mineral soils.

Key words: tree rings, dendroclimatology, event year, drought, bog, soil water, Scots pine

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 is 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 (Битвинскас 1974).

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

Dendroclimatological investigation on pine tree rings in Latvia (Шпалте 1978), Estonia (Läänelaid 1982, Läänelaid and Eckstein 2003), Poland (Cedro 2001, Cedro 2006) and Scandinavia (Linderson 1992) provided similar results that pine is sensitive to cold winters in the area around the Baltic Sea. However, rainfall during summer in Poland may induce wide rings of pine (Cedro 2001, Cedro 2006).

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 soil (Fritts 1987). Many studies have proven that pines on peat bogs respond to precipitation negatively, especially during summer time (Boggie 1972, Jasnowska 1977, Läänelaid 1982, Битвинскас 1974), but in several studies contradictory results have been found affirming positive, usually insignificant, impact of precipitation on pine radial growth on wet sites (Карпавичюс 1993, Linderholm 2001). This may be related to shallow root system of sites with high water table (Lieffers and Rothwell 1986). Trees may become less tolerant of droughts after the decrease in water level (Kozlowski 1997).

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 on pines growing on sites with high water table.

Material and methods

Research plots are located in the Aukštaitija National Park (north-eastern Lithuania). North-eastern Lithuania is characterised by the most continental climate conditions – the shortest period of vegetation (185-192 days) and coldest January-February (-5.0 to -6.8 °C) as compared to other regions of Lithuania. The territory of the national park was strongly affected by the last glacial withdrawal, which had left the rugged terrain. Smaller or bigger lakes and peat bogs usually are formed on the lowest sites of it.

The terrain, where research plots have been selected, is located between two small lakes – Žiegžmaris and Ešerinis in the 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

Figure 1. Map and location of research area in Lithuania scale (black square)

Table 1. Characteristics of research plots (soil and forest type, geographical coordinates (WGS 84) and number of cored trees

Plot number	Soil type	Forest type	Geographical coordinates		Number of trees
			Latitude (N)	Longitude (E)	
1-2o	Organic	*Myrtillo-sphagno-Pinetum*	55°25'53"	26°02'38"	10
3-4o	Organic	*Myrtillo-sphagno-Pinetum*	55°25'60"	26°02'38"	10
5m	Mineral	*Vaccinio-myrtillo-Pinetum*	55°25'64"	26°02'34"	10
6o	Organic	*Myrtillo-sphagno-Pinetum*	55°25'63"	26°02'39"	6
7o	Organic	*Myrtillo-sphagno-Pinetum*	55°25'67"	26°02'34"	10
8o	Organic	*Ledo-sphagno-Pinetum*	55°25'70"	26°02'33"	9
9m	Mineral	*Myrtillo-Pinetum*	55°25'71"	26°02'39"	10
10-12o	Organic	*Myrtillo-sphagno-Pinetum*	55°25'82"	26°02'28"	8

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 above sea level.

Several soil parameters have been investigated in the research area. The measurements of soil water level have been launched in research plots from 1997. This is done every ten days from spring to autumn (approximately from mid April to the 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, four cores from each tree in each plot were taken at the breast height. 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 series of individual trees and checked again for dating errors.

The long-term regression analysis seldom permits to evaluate the effect of contrast climate conditions (information contained in conspicuous single growth rings). For this purpose event year analysis by using method "normalisation in a moving window" proposed by H.F. Schweingruber has been performed (Schweingruber 1990, Schweingruber 1993, Schweingruber *et al.* 1990). Calculations have been accomplished using WEISER 1.0 computer program (I.G. Gonzales, Lugo) (Gonzales 2001). Index value for event year (i.e. year with narrow 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}; *stdew[window]* – standard deviaton of the ring width within window x_{i-2}, x_{i-1}, x_i, x_{i+1}, x_{i+2}.

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

For the analysis of arid conditions, climate values according to Utena Meteorological Station were used. For the estimation of droughts in spring and summer, a slightly modified method (Formula 2) proposed by Walter (1974) was adopted.

$$
\begin{array}{ll}
P_i \le T_i & \text{Extreme drought} \\
T_i < P_i \le 2T_i & \text{Drought} \\
2T_i < P_i \le 3T_i & \text{Arid conditions}
\end{array}
\qquad (2)
$$

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

Results

Dating of ring series within and among trees was very complicated but successful and eight pine chronologies were compiled (Fig. 2). The number of discovered wedging and missing rings is variable between research plots (Table 2). The lowest probability of wedging and missing rings is among pines growing on dry sites, characterized by mineral soil. 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-sphagno-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 is always deeper than 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 the peat bog, is highly acid (3.55 pH).

The average tree ring widths are around or bellow 1 mm (Table 2). This is related not only to predominating unfavourable growing conditions in highly acid environment and high water table, but also to overmature trees, which age reach 221 years (Table 2).

Relationships between the average depth of soil water in April-September and the radial growth of pines during 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 is only one statistically significant coefficient. The datum-level (0) of the soil water measurements is at ground level, thus the higher values indicate the abatement of soil water. The most stable and positive links have been dis-

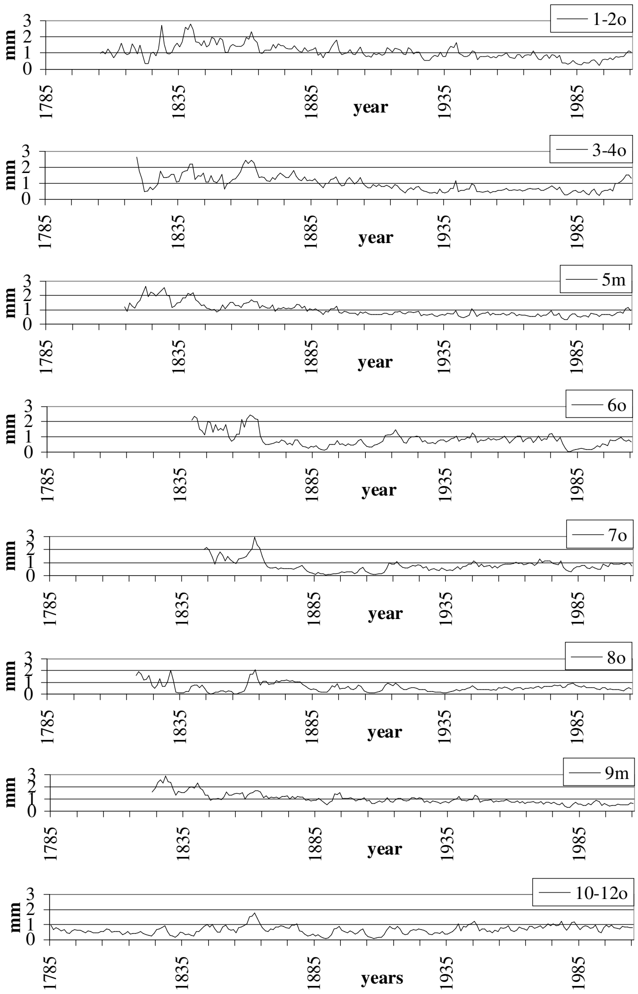

Figure 2. Eight chronologies (1-2o, 3-4o, 5m, 6o, 7o, 8o, 9m and 10-12o, in mm) of Scots pine growing under different site conditions

Table 2. Statistical characteristics of plots and tree-ring 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 number	Soil water level cm			pH value	Missing rings %	Tree ring width mm	Length of chronology years
	lowest	*average*	*highest*				
1-2o	76	32	4	3.42	0.59	1.09	201
3-4o	70	36	3	3.35	0.13	0.95	187
5m	247	226	201	6.05	0.06	0.98	192
6o	61	37	12	3.45	1.59	0.81	167
7o	80	51	21	3.30	0.48	0.73	163
8o	66	33	12	3.30	0.62	0.54	188
9m	89	72	51	4.35	0.00	0.99	183
10-12o	78	30	7	3.15	0.43	0.70	221

covered between soil water depth and the growth of pines on sites with mineral soil (5m and 9m) (Table 3). The increase in the growth is favoured by the abatement of the soil water depth during the vegetation season, *i.e.*, drier periods. The correlation between the radial growth of pines and water level on organic sites is much lower. Negative links are observed between the radial growth of pines and water level on wet sites (1-2o, 7o, 8o and 10-12o), which are located near the lakes. This indicates that the high water table stimulates the radial growth on wet sites.

Table 3. Coefficients of correlation between the average depth of soil water in April-September and the radial growth of pines at eight research plots during 1997-2005

Months	1-2o	3-4o	5m	6o	7o	8o	9m	10-12o
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
Jul	-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

Note: * - indicates significance - 95%

The average percentage of trees with a decrease in the radial growth from 1900 to 2005 on organic and mineral sites is presented in Table 4. Here we presented only years not inter-connected with winter colds. It is evident that the percentage of trees is variable among years, while the differences between organic and mineral sites are lower (Fig. 3) and statistically insignificant ($p \leq 0.05$). The most important for the formation of negative event years are droughts in May and June, while the significance of droughts in Au-

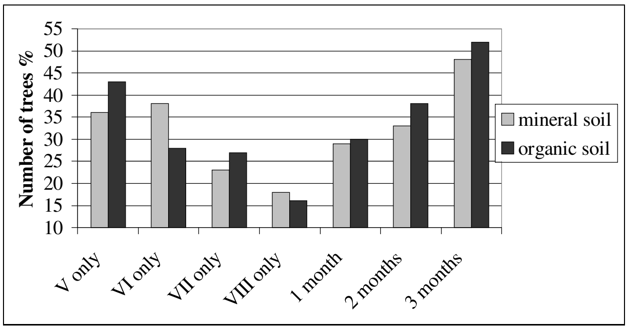

Figure 3. The average percentage of trees indicating negative event years (decrease of the radial growth) on mineral and organic soils during droughts. First four columns show average percentage of trees during droughts of one-month duration (May-August). The last three columns indicate percentage of pines with event years during droughts of different length (one month, two months and three months)

Table 4. Average percentage of Scots pines showing distinct decrease of the radial growth (event year) on organic (o) and mineral (m) sites during dry climate conditions in 1900-2005 not interconnected with winter colds. Droughts during May – August are expressed with abbreviations: extreme drought (ED), drought (D), arid conditions (A)

Year	Site conditions		Aridity, months				Year	Site conditions		Aridity, months			
	o	m	V	VI	VII	VIII		o	m	V	VI	VII	VIII
1900	66	40	D	A	A		1959	61	60	A		D	A
1901	64	35	D		ED		1961	17	20			A	
1904	18	35			A		1966	14	40		D		
1905	44	15		A			1971	79	75	ED		A	A
1906	56	50	A				1975	24	10	A			
1907	53	65	A				1977	41	35	A			D
1910	38	45	D		D		1978	0	0		A		
1911	44	40	ED			D	1979	26	35		D		
1914	34	80			A	ED	1982	34	5			D	
1918	37	30	ED				1983	6	0				ED
1919	70	65	D				1984	13	15				A
1920	77	65			A		1988	57	15	A			
1925	19	5	A				1989	58	100		D		
1927	15	20			A		1991	7	0			D	
1934	51	25		D		A	1992	54	25			D	D
1936	33	10	A	D			1993	85	95	ED			
1937	22	35	D			A	1994	4	15			ED	
1938	11	30	D	A		ED	1995	16	25				A
1939	0	0				ED	1996	41	40				ED
1946	3	0	ED				1999	28	30	A		ED	
1949	34	25			A		2000	29	20	A			
1951	8	5		A		D	2001	38	25			A	
1953	20	25				A	2002	44	60	D		ED	ED

gust is much lower. However, droughts in May and June of 1925, 1946 and 1978 did not provoke a marked decrease in the radial growth.

The duration of droughts is another important factor affecting the percentage of trees with event years. Droughts lasting for three months on average strongly affect 48-52% of pines on both organic and mineral sites. Droughts of one and two month's duration have affected 29-30% and 33-38% of trees respectively. The average percentage of trees with event years on mineral and organic soils is similar; the differences statistically are insignificant ($p \leq 0.05$).

Discussion

In spite of that living mature and over-mature trees are the most valuable sources for dendrochronological investigation, providing as long tree ring width series as possible, dating of such trees often is difficult, especially in the unfavourable environment (Pukienė 1997). Pine growth in peat bogs is characterised by narrow rings, which often transits into wedging rings on different sides of the stem. During the periods with unfavourable conditions in boggy sites missing rings are detected occasionally. Therefore, precise dating of measured tree ring series was successful mainly because of four taken cores per tree.

The frequency of wedging and missing rings is directly connected not only to the age of trees, but also depends on growing conditions of pines (Table 2). The least frequency of missing rings was established among pines growing on mineral soils, while the biggest – among pines on organic (peat) soils (Table 2). The negative relationships between the frequency of missing rings, soil water acidity and average depth of soil water also exist, but the coefficients are not significant statistically.

Because pine is ecologically very plastic species growing on almost all sites (Polacek *et al*. 2006), earlier investigations have been performed in different geographical regions and diverse site conditions. Dendroclimatological research on Scots pine in Lithuania has demonstrated that tree rings of pine are sensitive indicators of colds during winter and spring (Битвинскас 1974, Yadav *et al*. 1991, Vitas and Bitvinskas 1998). Other research have proven this feature, but herewith hypothesized that there is effect of droughts during summer on the tree ring widths of pine (Karpavičius *et al*. 1996, Vitas 2004a). Different results partly are connected to the long-term climate fluctuations: the period of cold winters (until 1986) and repeating summer droughts during the last decade of the 20th century, which are possibly provoked by global climate change (Hoerling and Kumar 2003, Hopkin 2004). Dendroclimatological investigations on pine tree rings carried out in neighbouring countries provided similar results that pine is most sensitive to cold winters (Шпалте 1978, Läänelaid 1982, Läänelaid and Eckstein 2003), while the influence of precipitation has a secondary importance (Cedro 2001, Cedro 2006, 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 the rate of photosynthesis (Percival and 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 the depth and fluctuations of the water table (Boggie 1972, Jasnowska 1977, Läänelaid 1982, Битвинскас 1974). Its depth is controlled by precipitation and temperature (Mannerkoski 1991). However, J. Karpavičius (Карпавичюс 1993) discovered positive impact of precipitation in July on tree rings of pine growing in the Žuvintas Strict Nature Reserve peat bog. This positive influence is probably due to shallow spreading root systems on sites with high water tables (Lieffers and Rothwell 1986). Therefore, after the decrease in water level plants may become less tolerant of droughts because of weakened absorption of water by small roots (Kozlowski 1997).

Coefficients of the correlation between the radial growth of pines and depth of soil water in most cases are statistically insignificant ($p=0.05$). This is also connected to quite short time of measurements (9 years). We found positive links between the soil water depth and the radial growth of pines on mineral sites (Table 3). This indicates that the growth of pines is stimulated by deeper water levels (drier periods) and high water table has negative effect on the radial growth. Coefficients between the radial growth of pines and water depth on organic sites are much lower. Negative links have been observed on the wettest plots (1-2o, 7o, 8o and 10-12o). The high water table stimulates the radial growth on sites with organic soil. It might be interpreted that pines on sites with organic soil could be more sensitive to the abatement of soil water compared to sites with mineral soil.

We have analysed years (not inter-connected with winter colds) with droughts during the 20th century.

The percentage of trees with a decrease in the radial growth during droughts in most years is similar between sites with organic and mineral soils (Table 4). Droughts in May and June are much more stressful than in August and percentage of affected trees on both organic and mineral sites on average is similar (Fig. 3). However, in 1925, 1946 and 1978 droughts in May and June did not cause marked reduction of the radial growth. We think that this may be connected to short duration of droughts and favourable conditions before and after droughts: (i) mild winter in 1925, (ii) snowy winter with higher accumulation of water and humid June after drought in 1946, (iii) snowy winter and humid April before the drought in 1978.

The duration of droughts is a very important factor. The most dangerous are droughts lasting for three months (on average cause a marked decrease for 48-52% of pines), while droughts lasting for one month usually affect about 30% of trees only. The average percentage of trees indicating negative event years on sites with organic and mineral soils is similar.

Summarizing stated above we conclude that our investigation did not reveal significant differences in the response of pines to the droughts on sites with organic and mineral soils. Probably, the sensitivity of pines to droughts on sites with peat soils is connected to the specific growing conditions. Shallow root system might be responsible for the intolerance of pines to the decrease in the soil water table.

Conclusions

1. The investigations have revealed that the fluctuations of the soil water level influence the radial growth of pines: the increase in the water table stimulates the radial growth on sites with organic soil, while on sites with mineral soil high water table has an inverse effect.

2. Dendroclimatological research has revealed that droughts in May and June are more dangerous and induce higher number of pines with marked decrease of the radial growth compared to droughts in August.

3. The most dangerous are droughts of three months duration, while droughts of one-month length usually are not so stressful. The influence of drought, expressed as percentage of pines with event years, depends on climate conditions before and after the drought. Favourable conditions may reduce or even eliminate negative effect of short one-month droughts to the tree rings of pines.

4. We did not find statistically significant differences in the response of the radial growth of pines to droughts growing on sites with organic and mineral soils.

Acknowledgements

I am grateful to my colleague – engineer ecologist E. Šimkūnienė for the long-term measurements of the soil water level in research plots.

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Received 13 December 2006
Accepted 17 May 2007

ВЛИЯНИЕ ЗАСУХ НА РАДИАЛЬНЫЙ ПРИРОСТ СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS* L.) В РАЗЛИЧНЫХ МЕСТАХ ПРОИЗРАСТАНИЯ

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Резюме

Дендроклиматологические исследования на радиальный прирост сосны обыкновенной были проведены в северовосточной части Литвы в Национальном парке Аукштайтии. Целью исследования явилась оценка различий влияния засух на радиальный прирост сосен, растущих на сухих и на влажных местах произрастания. Влияние засух было исследовано при помощи анализа лет происшествия. Исследования показали, что флуктуации уровня воды в почве действует по разному на прирост сосны. Повышение уровня воды стимулирует радиальный прирост сосен, растущих на органических почвах, в то время как на минеральных почвах понижение уровня воды на прирост действует позитивно. Мы устоновили, что засухи весной и ранним летом (Май-Июнь) являются более опасными на прирост сосны, чем засухи в августе. Засухи, продолжающиеся три месяца являються более стрессовыми, чем продолжительностю одного месяца. Влияние засух на радиальный прирост сосны, также зависит от климатических условий перед и после засухи. Исследования не устоновили заметных разностей в количестве деревьев подверженных влияниям засухи, произрастающих на органических и на минеральных почвах.

Ключевые слова: радиальный прирост, дендроклиматология, год происшествия, засуха, болото, вода почвы, сосна обыкновенная