

MONITORING OF *PINUS SYLVESTRIS* L. AND *P. NIGRA*
ARN. FROM MALESHEVSKA MOUNTAIN USING
DENDROCHRONOLOGY AND CLIMATIC DATA

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Abstract

The conducted analysis is related to the stress periods, the functional type of trees, as well as climatic types of years and climatic patterns identification to obtain the existing risk for the forest stands. Thirty-nine Scots pine trees and ninety-six black pine trees were sampled from the Sokolata reserve and the area near the village of Igralishte in Maleshevska Mountain, Southwest Bulgaria (longitude 23.1–23.13; latitude 41.5–41.6 and altitude 860–950 m). The obtained common stress years for Scots pine were 1980, 1991, 1993, 1994, 2004, 2007, 2012, and for the black pine – 1988, 1996, 2003, 2012, 2013, 2015. The received average functional types for Scots pine were, respectively, trees with very rare eustress occurrence, very short duration, and normal or deep amplitude. There is some risk for the trees from Igralishte village due to the available deep eustress. The obtained average functional types for the black pine were, respectively, trees with very rare eustress occurrence, very short duration and very small depth or very deep amplitude – A1 and A5. There is a risk for the black pine trees from Igralishte village due to the available very deep eustress. For Scots pine, two consecutive cold years and a third cold and wet one, as well as three consecutive cold and wet years, led to the onset of eustress. Other critical situations included the alternation of cold and wet years with warm and wet ones and vice versa, or the alternation of warm and dry two-year periods with a cold and wet climate. For the black pine consecutive dry years exert a stressful influence, as well as the alternation from dry to wet and warm years. Cold years and cold and wet years had a critical influence.

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Key words: pines, growth index, eustress, functional tree type, climatic year type

Introduction. Monitoring of ecosystems of Scots pine (*Pinus sylvestris*) and Black pine (*Pinus nigra*) involves systematic observation and assessment of various ecological factors to understand their health, dynamics, and responses to environmental changes. By systematically monitoring, researchers and land managers can understand ecological dynamics, resilience, and vulnerabilities of ecosystems, that support decision-making for conservation, management, and restoration purposes. The used data should be standardized, consistent, and conducted over long-term time scales to detect trends and patterns. The collected meteorological data, such as temperature, precipitation, and others, within Scots pine and black pine ecosystems help to analyze long-term climatic trends and extreme weather events that may impact the ecosystems state and dynamics. By integrating dendrochronological analysis with climatic data, monitoring programmes can provide comprehensive assessments of Scots pine and Black pine ecosystems, helping to understand their growth patterns, responses and vulnerability to environmental changes, overall health, and ecological forest dynamics, as well as support conservation strategies, ecosystem services dynamics, and management interventions. Tree-ring width measurement, cross-dating, and statistical analysis are fundamental techniques used to construct tree-ring chronologies that provide sufficient standardized data to extract environmental signals.

There are a lot of investigations concerning climate-growth relationships or relationships between climate variables (such as temperature, precipitation) and tree growth using statistical methods. A recent one reported on a substantial decrease in the tree-ring index fluctuations and a growth cyclicality loss in the last thirty years [1]. The results also evinced that mean air temperature was the most important factor influencing the radial growth. By [2] daily temperature and precipitation data more precisely showed climate-growth relationships than monthly ones. The precipitation and temperature of March had the strongest influence on ring widths. The growing season of Scots pine in Northern Poland started in February–March and extended to June–July depending on the rainfall. Using annually-resolved Blue Intensity (BI) measurements, black pine and Scots pine on the Iberian Peninsula were investigated [3]. It was found that the series were more sensitive to summer drought at low-elevation sites and trees from Andalusia and Central System formed the elevation groups. In February and October temperatures were the limiting growth factor for the high elevation sites, while for low-elevation trees it was the average winter temperatures. DUKIĆ et al. [4] registered a negative effect of temperature (except in winter months) and a positive effect of precipitation, as well as a significant impact of moisture deficiency on the tree ring formation in the period from June to August for Scots pine. The use of black pine tree-ring data for reconstructing past spring precipitation in the

Western Mediterranean basin [5], highlights the potential of dendrochronology for climate reconstructions in regions, where historical climate data are limited. Thus the developed dendro-climatic models can reconstruct or predict past or future phenomena and provide valuable insights into tree growth and forest dynamics. The climate-growth relationship in tree-ring width chronologies from black pine and Scots pine trees and wood anatomy of the last one have been studied [7–9] in three mountains of Bulgaria. The significant negative correlations with temperatures and high positive – with precipitation in the summer, as well as the stable drought signal in the constructed chronology were obtained for the black pine.

The aim of investigation was to obtain the eustress years (decreased stem growth) and their relationships with climatic types of years by temperature and precipitation [10, 11] in Maleshevska Mountain. Through three characteristics of stress periods – duration, frequency per 100 years, and amplitude (depth), the dominant functional type and the risk for the forest existence could be determined.

Object and methods. The objects of research were the stands of *Pinus sylvestris* L. and *P. nigra* Arn. in Maleshevska Mountain, Southwest Bulgaria (longitude 23.1–23.13; latitude 41.5–41.6 and altitude 860–950 m) (Table 1). According to the phytogeography zoning [12], these forests fall within the Middle Struma Area of the Mediterranean Sclerophyllous Forest Region. The investigated region is included in the Submediterranean climatic area, characterized by warm and dry summer, mild winter and thin snow cover [13]. The soils in the mountain are chromic cambisols, medium and highly eroded [14]. Coniferous species were planted to diversify the landscape in the area, but some of them have a natural origin. Thirty-nine Scots pine trees and ninety-six black pine trees were sampled from the Sokolata reserve and the area near the village of Igralishte, with ages ranging from 34 to 53 years and 32 to 62 years, respectively. The diameter variations were between 31.12 and 32.23 cm for Scots pine and 27.58 and 32.79 cm for the black pine. The obtained values of EPS (Expressed Population Signal) indicated that the sampled species are sufficient for the conducted analysis.

Dendrochronological samples were taken by Presler's auger at a height of 1–1.5 m and they were mounted on wooden patterns with 4 grooves with sizes 50/5/2 cm. The disks cut from stems were also used. The samples and disks were polished with sanders and sandpaper before measurement. The measuring of annual ring widths of the samples was by LINTAB 6 Tree ring station with an accuracy of 0.01 cm. Sampling and measurement were under methodological guidance [15–17]. Data processing and dating were made according to the methodological requirements [18], using TSAP-Win software, program COFECHA and the next processing and analysis – by SPPAM program version 2.0 [19]. Data with implausible values (outliers) were eliminated. Climatic data were from on-line data base www.stringmeteo.com for 1901–2019, for which period the climatic analysis was done.

Results and discussion. The Scots pine tree ring width series (10 from

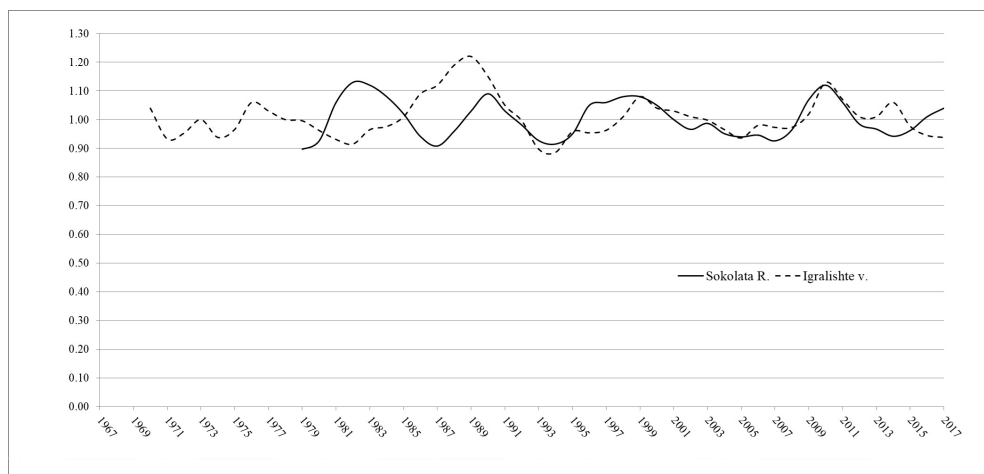
T a b l e 1
Objects characteristics

Sampling area (SA)	Long., °	Lat., °	Alt., m	T _{av.} , °C	P _{av.} , mm	Period from, y	Period to, y	Age _{min} , y	Age _{max} , y	DBH, cm	N	EPS %
<i>Pinus sylvestris</i> L.												
Sokolata R.	23.10	41.54	950	9.32	604.73	1975	2018	34	44	31.12	10	85.28
Igralishte v.	23.13	41.57	860	8.93	616.27	1966	2018	34	53	32.23	29	91.93
<i>P. nigra</i> Arn.												
Sokolata R.	23.10	41.54	940	9.02	612.06	1972	2017	32	46	27.58	35	95.07
Igralishte v.	23.12	41.58	950	8.65	622.29	1957	2018	45	62	32.79	61	96.78

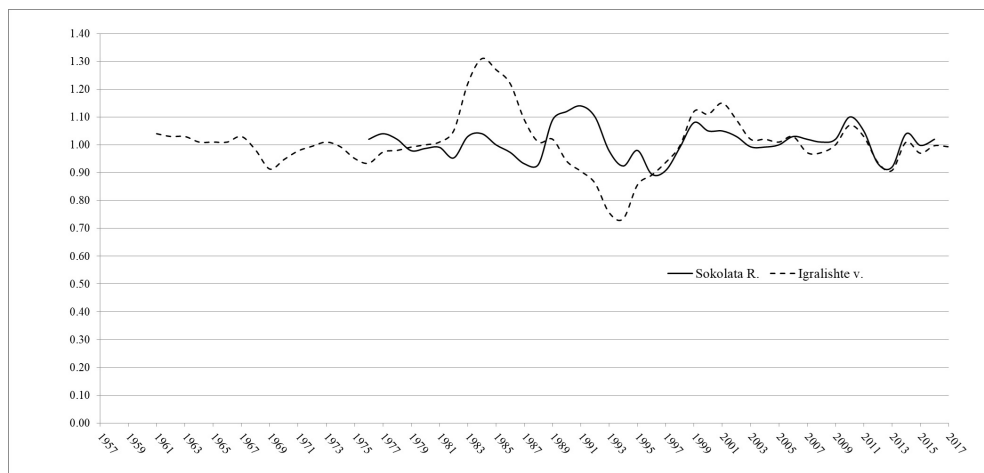
Sokolata reserve, SR and 29 from the region of Igralishte village, IV) had the approximating polynomials with 6 degree and R^2 was between 0.45 and 0.88. The black pine tree ring series (35 from SR and 61 from IV) had the approximating polynomials, respectively, with 5 to 7 degree and R^2 was between 0.48 and 0.89; polynomials with 6–7 degree and R^2 between 0.52 and 0.89. Three of the series of Scots pine (2 from SR and one for IV) and four series of black pine (three from SR and one from IV) had $R^2 < 0.45$ and were excluded from further analyses. The average index variation by sampling areas and years was shown in Fig. 1. As could be seen, due to the younger age of the rows of SR the growth had some divergence in direction and greater intensity in the first periods (Fig. 1AB). The correlation coefficient between the SR and IV average index rows was 0.141 and 0.209, respectively, for Scots pine and black pine, i.e. weak correlation. The average growth index formed rows from both probed locations of two species. It was 1.004 for Scots pine, and 1.005 for the black pine. The correlation coefficient between two formed rows of Scots pine and black pine was 0.497, i.e. moderate correlation (Fig. 1C).

The average index for SR and IV, belonging coefficients and the number of obtained stress years (SY) were shown in Table 2.

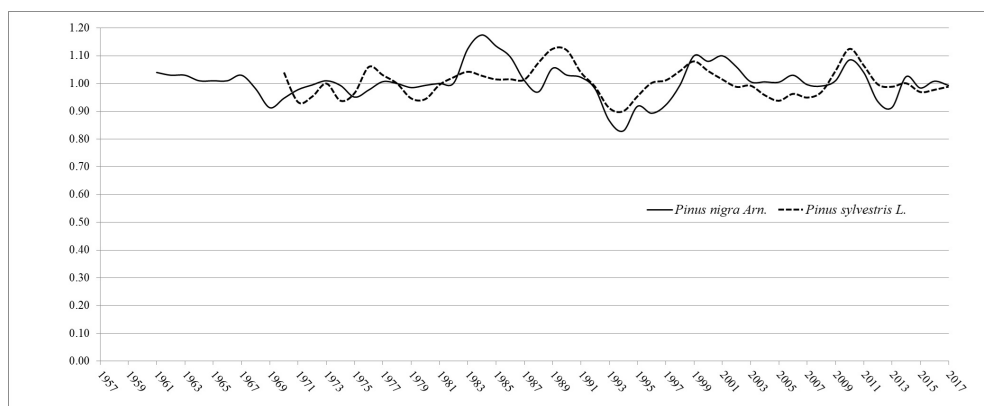
For Scots pine within 39 and 48 years, totally 6 stress periods with 12 stress years (average duration of 2 y, max of 6 y and min of a year) and 10 stress periods with 17 stress years (average duration 1.7 y, max of 2 y) were obtained for SR and IV, respectively. For black pine within 42 and 57 years, totally 7 stress periods with 11 years (average duration of 1.6 y, max of 4 y and min of a year) and 10 stress periods with 17 stress years (average duration 1.7 y, max of 5 y) were obtained for SR and IV, respectively. The common stress years for Scots pine were 1980, 1991, 1993, 1994, 2004, 2007, 2012 and for black pine – 1988, 1996, 2003, 2012, 2013, 2015. Average characteristics of eustress for both species using



A



B



C

Fig. 1. Variation of average index for A – *Pinus sylvestris* L., B – *P. nigra* Arn., and C – for both sampling areas

T a b l e 2

Characteristics of the investigated series

Species/SA	Period (P)	I_t av	$m_{t_{av}}$	SY^*_n	$Card_{av}^{**}$	Cov_{av}^{***}	$Ct = Card_{av}/N$	$K = P/SY$
<i>Pinus sylvestris</i> L.								
Sokolata R.	39	1.003	0.098	12	4.231	0.648	0.529	3.250
Igralishte v.	48	1.006	0.091	17	14.667	0.587	0.524	2.823
<i>P. nigra</i> Arn.								
Sokolata R.	42	1.009	0.137	11	19.154	0.623	0.599	3.818
Igralishte v.	57	1.005	0.085	17	37.857	0.672	0.631	3.353

Legend: *Eustress year – the year for which statistically proven decreasing of I_t under 1 was identified; **cardinality – the number of sequences that had the same stress years; ***coverage – the ratio between Card and the number of investigated sequences, which included the same periods

the five graded scale (Table 3) were as follows:

For both plots of *P. sylvestris* L. – SR and IV, A_{av} was 0.273 and 0.268, respectively; A_{max} – 0.365 and 0.582 for 1991 and 1971; D_{av} – 2 and 1.7 years, as D_{max} was 6 and 2 y for 1991–1995 (Sokolata R.) and: 1980–1981, 1990–1991, 1993–1994, 2004–2005, 2007–2008, 2011–2012, 2004–2005, 2007–2008, 2011–2012, 2015–2016 (IV); F_{av} for 100 y was 29 and 32. The obtained average functional types (PFTs) for Scots pine was F1D1A3 and F1D1A4 for SR and IV, respectively, trees with very rare eustress occurrences (F1), very short duration (D1) and normal or deep amplitude (A3 and A4). There is some risk for the trees from IV due to the available deep eustress.

For both plots of *P. nigra* Arn. – SR and IV, A_{av} was 0.253 and 0.310, respectively, as A_{max} was 0.390 for 2012 and 0.496 for 1993; D_{av} was 1.6 and 1.7, as D_{max} – 4 for 1985–1988 and 5 for 1990–1994, respectively; F_{av} for 100 y was 26 and 30 y. The obtained average functional types (PFTs) for black pine was F1D1A1 and F1D1A5, respectively, trees with very rare eustress occurrences (F1), very short duration (D1) and very small depth or very deep amplitude (A1 and A5). There is risk for black pine trees from IV due to the available very deep eustress.

For the studied period, the cold years predominated (56–58% for two species in SR and 53–54% for IV), among them the wet ones were at the first place (CW, 31–34 % and 26–31%, respectively). The hot years were 20–21% and 21–25% for SR and IV, as hot and dry years varied from 10 % to 11–13% (IV).

We have examined the climatic types of stressful years (SY) and both years

T a b l e 3

Five-graded scale for assessment of eustress features

Frequency			Duration			Amplitude		
<i>Pinus sylvestris</i> L.								
Group	Name	Value	Group	Name	Value	Group	Name	Value
1	Very rarely	≤ 38.85	1	Very short	≤ 2.30	1	Very small depth	≤ 0.25
2	Rarely	$> 38.85 - \leq 40.31$	2	Short	$> 2.30 - \leq 2.42$	2	Small depth	$> 0.25 - \leq 0.26$
3	Normal	$> 40.31 - \leq 43.22$	3	Normal	$> 2.42 - \leq 2.65$	3	Normal depth	$> 0.26 - \leq 0.27$
4	Often	$> 43.22 - \leq 44.67$	4	Long	$> 2.65 - \leq 2.76$	4	Deep	$> 0.27 - \leq 0.28$
5	Very often	> 44.67	5	Very long	> 2.76	5	Very deep	> 0.28
<i>P. nigra</i> Arn.								
1	Very rarely	≤ 39.07	1	Very short	≤ 2.20	1	Very small depth	≤ 0.26
2	Rarely	$> 39.07 - \leq 41.19$	2	Short	$> 2.20 - \leq 2.33$	2	Small depth	$> 0.26 - \leq 0.27$
3	Normal	$> 41.19 - \leq 45.43$	3	Normal	$> 2.33 - \leq 2.60$	3	Normal depth	$> 0.27 - \leq 0.30$
4	Often	$> 45.43 - \leq 47.56$	4	Long	$> 2.6 - \leq 2.73$	4	Deep	$> 0.30 - \leq 0.31$
5	Very often	> 47.56	5	Very long	> 2.73	5	Very deep	> 0.31

preceding them (SY-1 and SY-2) – climatic pattern to see under what regimes the stress occurs. For two sampling plots of Scots pine, respectively, 11 and 17 patterns were obtained, considering the common stressful years – 1980, 1991, 1993, 1994, 2004, 2007, and 2012. Two consecutive cold years and a third cold and wet one, as well as three consecutive cold and wet years, led to the onset of eustress. Other critical situations included, for example, the alternation of cold and wet years with warm and wet ones and vice versa, or the alternation of warm and dry two-year periods with a cold and wet climate. In the latter case, the highest amplitudes were recorded – 0.332 and 0.365.

For both sampling plots of the black pine, the same number of patterns was obtained – 11 and 17, with attention paid to the common stressful years – 1988, 1993, 1996, 2003, 2012, 2013, and 2015. The consecutive dry years exert a stressful influence, as well as the alternation from dry to wet and warm years. Cold years and cold and wet years had a critical influence, where the largest amplitudes were observed – 0.496 and 0.300.

This original study investigates the complex influence of temperature and precipitation, as in the nature, on annual rings. In addition, in ecosystems, the set of stress periods depends on the age of trees, the period of years in which the study is carried out and a number of other factors – soil, ecoclimate, cohabitants and phytocenotic conditions, pathogens, anthropogenic impact, etc. For this reason, the comparison with other studies in other regions and for other periods is not correct.

Conclusion. Thirty-nine Scots pine trees and ninety-six black pine trees were sampled from Sokolata reserve and the area near the village of Igralishte in Maleshevska Mountain. The correlation coefficient between investigated Scots pine and black pine average index rows from both sampled plots was 0.497, i.e. moderate correlation.

For Scots pine within 39 and 48 years, 6 and 10 stress periods with 12 and 17 stress years were obtained, respectively, for Sokolata Reserve and the region of Igralishte village. For the black pine within 42 and 57 years, totally 7 and 10 stress periods with 11 and 17 stress years were obtained, respectively, for Sokolata Reserve and Igralishte village. The common stress years for Scots pine were 1980, 1991, 1993, 1994, 2004, 2007, 2012 and for black pine – 1988, 1996, 2003, 2012, 2013, 2015.

The obtained average functional types (PFT) for both species were, respectively, trees with very rare eustress occurrences (F1), very short duration (D1), and normal or deep amplitude (A3 and A4) for Scots pine, and very small depth or very deep amplitude (A1 and A5) for the black pine. There is a risk for Scots pine and black pine trees from the region of Igralishte village due to the available deep eustress.

For Scots pine, two consecutive cold years and a third cold and wet one, as well as three consecutive cold and wet years, led to the onset of eustress. Other

critical situations included the alternation of cold and wet years with warm and wet ones and vice versa, or the alternation of warm and dry two-year periods with a cold and wet climate. For the black pine consecutive dry years exert a stressful influence, as well as the alternation from dry to wet and warm years. Cold years and cold and wet years had a critical influence.

Thereby, investigating dendrochronological and climatic data of different sites, forest types, or species can reveal growth responses to climate variability that helps identify most critical for the growth and resilience of Scots pine and black pine ecosystems climatic periods. The identifying eustress periods give the possibilities to conduct management strategies, while understanding long-term growth trends – to perform sustainable harvesting and conservation practices.

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