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DENDROCHRONOLOGY AS A TOOL FOR THE INVESTIGATION OF FOREST DECLINE

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Abstract

The forest cover of Bulgaria is characterized by great diversity. Both conifers and broadleaves show reduced vitality. Among all tree species, Pines, Silver fir and deciduous Oaks are the most damaged. Our research was based on the hypothesis that forest decline is caused by multiple stresses affecting the ecosystem. With such stress-caused diseases, a distinction was done between predisposing, inciting and accompanying stress factors. Dendrochronology was used for extracting ecological information from dated tree rings. No single factor has been clearly identified as the cause of the forest decline. Among the important predisposing factors was the drought. However, other factors such as fungal diseases, insect damages and mistletoes played part in the forest decline. Studies into these aspects showed that air pollution also plays a part in the deterioration of forest health.

Key words: forest decline, dendrochronology, multiple stresses, Scots pine, oaks.

Introduction

Forests in Bulgaria cover one third of the country's area and are characterized by one of the highest tree diversity in Europe (MCPFE 2007). Some of main tree species in the country are Pines and Oaks. Pine stands cover one-sixth of the woodland and more than 50 % of the land, occupied by coniferous forests (Rafailov 2001). Pines were also the main species that have been used in the large scale afforestration in Bulgaria during the 20th century. Almost twice larger area is occupied by oak forests – about one third of the woodland and more than 42 per cent of the land, occupied by broadleaved forests.

During the last decades both coniferous and broadleaved forests showed reduced vitality. This raised scientific awareness and led to growing number of studies, but the causes leading to the declining forest health condition remain not fully clarified. Some of the scientists attribute it to fungal diseases and insect infestations, while others to abiotic factors, including inappropriate environmental conditions and climate change. The disadvantages of these approaches led to development of new concepts for the forest health and factors affecting it. An important contribution in this direction is the concept of forest decline, according to which tree diseases result from multiple interacting factors that can be grouped into three categories: predisposing, inciting and contributing (Manion 1981, Mirtchev 1991).

The most precise way to investigate the influence of variety of environmental factors on trees is by considering time scale. The environmental situation is shown in true light only by tree rings (Schweinguber 1996), which makes dendrochronological methods most suitable for studying the impact of the factors, affecting tree health (Mirtchev 1991, Mirtchev et al. 2000).

The **objective** of this work was to study the influence of the main stress factors on the health condition of Pine and Oak forests in Southwestern Bulgaria. For this purpose, several **research tasks** were set:

- To analyze the dynamics of radial increment and health condition of the studied trees in the past;
- To assess the effect of temperature-precipitation regime, air pollution, fungal diseases and insect damages on the health condition of the stands, and
- To develop mathematical models for prediction of the radial increment of trees.

Materials and Methods

Objects of this study were Scots pine (*Pinus sylvestris* L.) and Hungarian oak (*Quercus frainetto* Ten.) stands in the mountains of Southwestern Bulgaria. Samples were taken from 15 pine stands of varying ages and growing under different ecological conditions. The altitude varied from 600 to 2000 m a.s.l. Samples were also collected from 1 oak stand, located at 750 m elevation in the Sokolata reserve.

Dendrochronological methods, as described by Fritts (1976) and Cook and Kairiukstis (1990), were used for sampling the trees and processing and cross-dating the cores. Twelve to seventeen trees per stand were sampled and one or two cores per tree were extracted. Tree-ring widths were measured to the nearest 0.01 mm using a tree-ring measuring table equipped with DendroMeasure computer program in the University of Forestry, Sofia.

Statistical analysis of the obtained ring-width series was implemented by means of software products MS Excel, StatSoft Statistica 6.0 and DendroStat (Zafirov 2008), under a scheme, proposed by Mirtchev et al. (2000). Multiple regression analysis was performed for assessment of climate influence on tree growth. As predictors in the models the following variables were used: mean monthly temperatures and monthly precipitation over a period of 15 months – from July previous year to September current year. Climate data of mean monthly air temperatures and monthly precipitation were provided for the nearest available hydro-meteorological stations: Cherni Vrah (2286 m a.s.l), Sofia (552 m a.s.l), and Sandanski (191 m a.s.l).

Mathematical models for prediction of the tree radial increment were developed using intrasystemic approach (Cook and Kairiukstis 1990). For this purpose the cyclic recurrence in the mean index chronologies was studied by means of spectral analysis (Cook and Kairiukstis 1990, Kairiūkštis and Venclovienė 2000).

Results and Discussion

The procedures for detrending of tree's radial increment revealed that the Modified exponential function is the most reliable one for removing the age-related trend in most of the series (Fig. 1, upper chart).

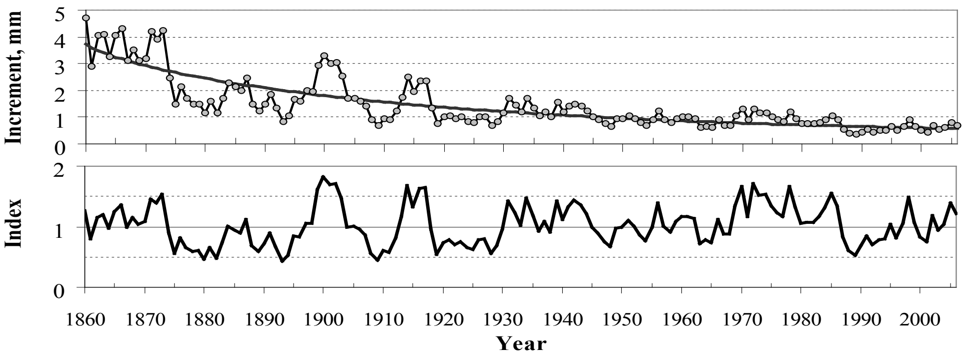

Fig. 1. Tree-ring width and index dynamics for one Scots pine tree.

Tree-ring width series were transformed into new index chronologies using the ratio between the values of radial increment and analogous values from the selected trend lines (Fig. 1, lower chart).

The individual index series for Scots pine trees were averaged together into two mean index chronologies – for the stands growing at high and at low elevations (above and below 1000 m a.s.l., respectively) (Fig. 2). These chronologies represent the dynamics of radial increment of the stands. The indices have mean value around 1 and fall below that value during periods of growth depressions (stress periods) (Mirtchev et al. 2000).

Analysis of the two mean chronologies revealed 5 growth depressions for the studied Scots pine stands during 20th century. The trees at higher elevations were stressed during the following periods: 1905–1909, 1924–1935, 1942–1972 (with a short interruption around 1960) and 1984–1990. For the trees at lower elevations stress periods were as follows: 1901–1909, 1916–1935, 1942–1953, 1961–1969 and after 1985. These periods for the trees at higher elevations were longer and even overlapped during the middle part of the century, while for the trees at lower elevations they were longer during its beginning and end. After the beginning of the current 21st century the trees in both groups were in poor health condition.

Combined and individual influence of mean monthly temperatures and monthly precipitation on the radial increment of the two groups of stands was studied by means of multiple regression analysis. The obtained coefficients of determination (R^2) for the combined influence increased from 0.62 for the trees at higher elevations to 0.73 for the ones at lower elevations (Fig. 3, upper chart). These values show that climate accounts for most of the variance in the index chronologies and define it as the most important factor, affecting Scots pine in the study area. Its higher influence on the stands at lower elevations qualifies it as primary stress factor for their decline.

The analysis of individual influence of temperature and precipitation on the radial increment showed that it was higher for both factors at lower elevations (Fig. 3, middle and lower charts). However, at higher elevations the influence of the mean monthly temperatures was higher, while at lower elevations so was the influence of monthly precipitation.

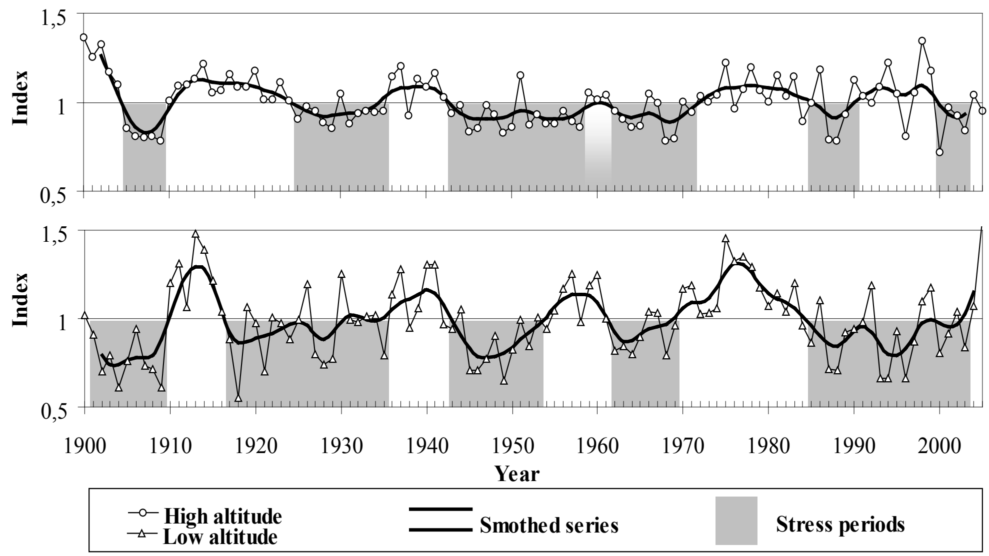

Fig. 2. Mean index chronologies for the radial increment of Scots pine stands, growing at high and low elevations, smoothing lines, and stress periods.

For one of the stands located near the village Yundola at 1350 m a.s.l, correlation between the changes in trees' radial increment and the variation of several atmospheric pollutants was analyzed (Table 1). Significant negative correlations were obtained only between the ring-width indices and O_3 and AOT40 (index, which is used for the purposes of vegetation and ecosystems protection and is calculated on the basis of measured O_3). This shows that the increase of the tropospheric ozone at this

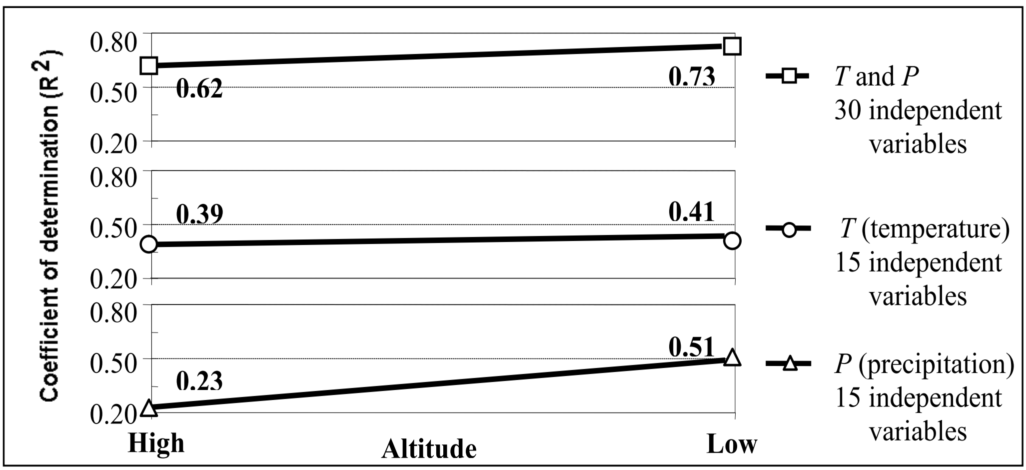

Fig. 3. Temperature and precipitation influence on the radial increment of the studied Scots pine stands.

location during the last years had negative effect on the studied Scots pine stand.

Several studies of Scots pine health in the Swiss Alps revealed that biotic factors have also played part in its decline mainly as contributing factors (Dobbertin et al. 2007). However, the damaging agents were not commonly distributed in whole study area and their impact on the stands was not studied.

Table 1. Influence of air pollution on the tree radial increment.

Year	Index	NO_x	SO_2	O_3	AOT40
1998	1.27	2.15	1.90	-	1.19
1999	1.42	1.52	1.46	6.39	0.95
2000	0.75	1.50	2.21	9.15	2.72
2001	1.12	1.58	1.53	7.57	2.22
2002	0.86	2.21	2.60	8.56	3.11
2003	0.89	1.21	1.37	9.33	3.87
2004	1.16	1.64	3.53	9.21	3.62
2005	1.12	1.37	3.32	8.99	3.18
2006	1.05	3.52	3.21	8.78	3.00
2007	1.16	4.40	3.67	9.86	3.26
2008	1.37	2.60	4.18	8.99	3.95
Coefficient of correlation (*r*)	-	0.16	0.20	**–0.44**	**–0.37**

Remark: the coefficients of correlation in bold are defined as moderate according to Mirtchev et al. (2000).

The recurrence of cyclic components in the two mean index chronologies was studied by means of spectral analysis and models for the changes of the radial increment were developed. The five main cyclical components in each series based on the obtained periodograms were selected for the development of the prognistic models (Cook and Kairiukstis 1990). The resultant model curves were close to the smoothed mean index chronologies for their common period (Fig. 4), which was confirmed by correlation analysis ($r = 0.76$ with $p = 0.00$ for high altitude and $r = 0.82$ with $p = 0.00$ for low altitude) and t-test for dependent variables (the mean values are not statistically significantly different – p is much higher than 0.05 for both altitudes). These statistics allowed the use of the developed models for long-term forecasts of the future changes of increment. The extrapolated model curves until 2020 show, that in the years around 2010 the trees in both groups are passing through stress period. It is longer and more pronounced for the stands at lower elevations. This period will last until 2012–2013, whereupon the less affected trees in both groups will recover and their radial increment is expected to rise above the average. During the end of 1910s a new decline of the radial increment is possible to begin.

The same dendrochronological methods were used for analysis of the ring-width series from the Oak stand. Separate index series were obtained for the radial increment of the trees and were averaged into a mean index chronology. The resultant chronology covers the period after 1800 and reveals several stress periods for the oak stand (Fig. 5). During the 19th century the growth depressions are as follows: 1805–1815, 1831–1844, 1851–1870, and 1876–1895. During the 20th century only two stress periods were observed and they coincide with the de-

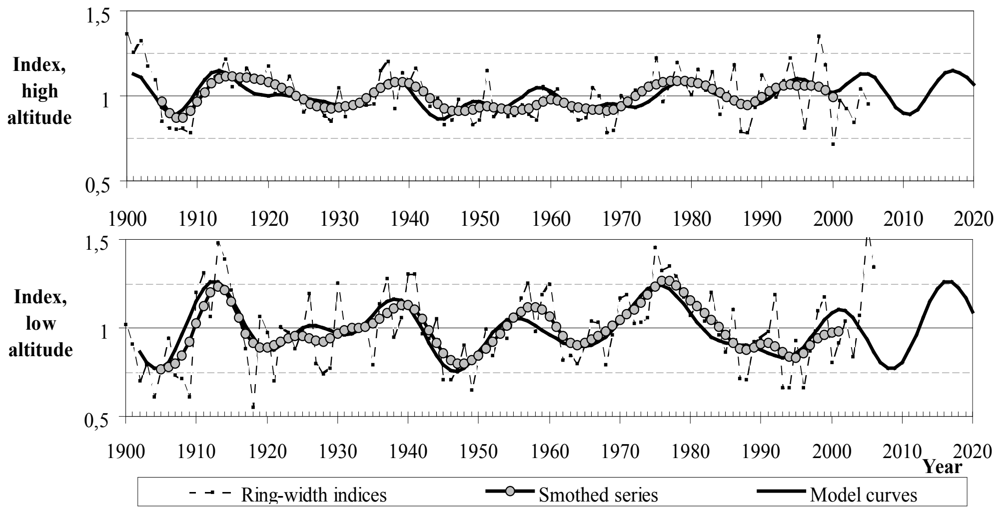

Fig. 4. Long term forecasts for the radial increment of Scots pine at high and low elevations in the study area.

scribed above growth depressions for the Pine stands: 1942–1959 and 1984–1993. The other stress periods, observed in the Pine chronologies, were not reflected in

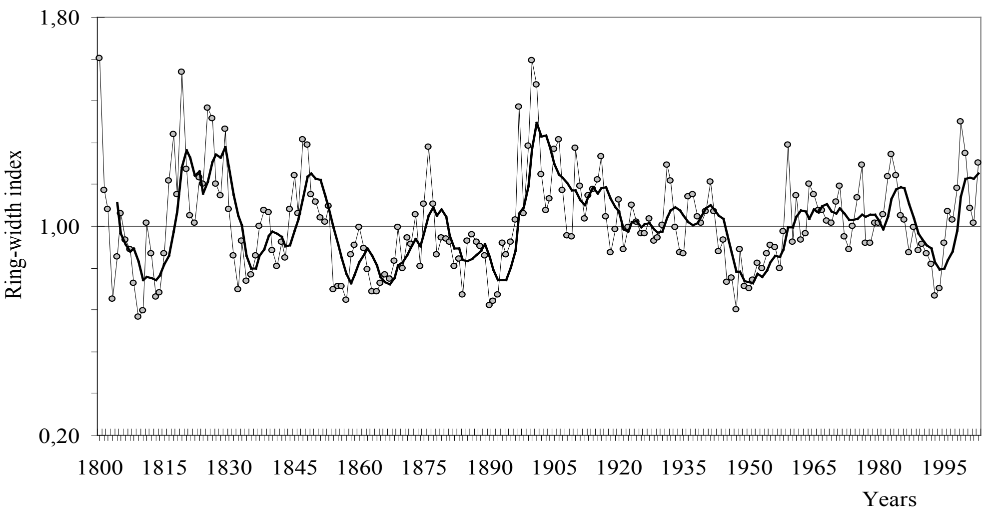

Fig. 5. Mean index chronology for the radial increment of the Oak stand (gray circles) and smoothing line.

the oak chronology, although for many years during these periods the oak increment was also below the average.

Multiple regression analysis was used in order to achieve clarifying of the "climate-growth" relationship. It revealed that the climate had an important effect on the changes of Oak radial increment (R^2 = 0.38) and on its health condition, respectively. The influence of monthly precipitation on the radial increment was more significant than that of the mean monthly temperatures. The graphical presentation of the regression coefficients of the developed mathematical model (Fig. 6) showed strong positive influence of the precipita-

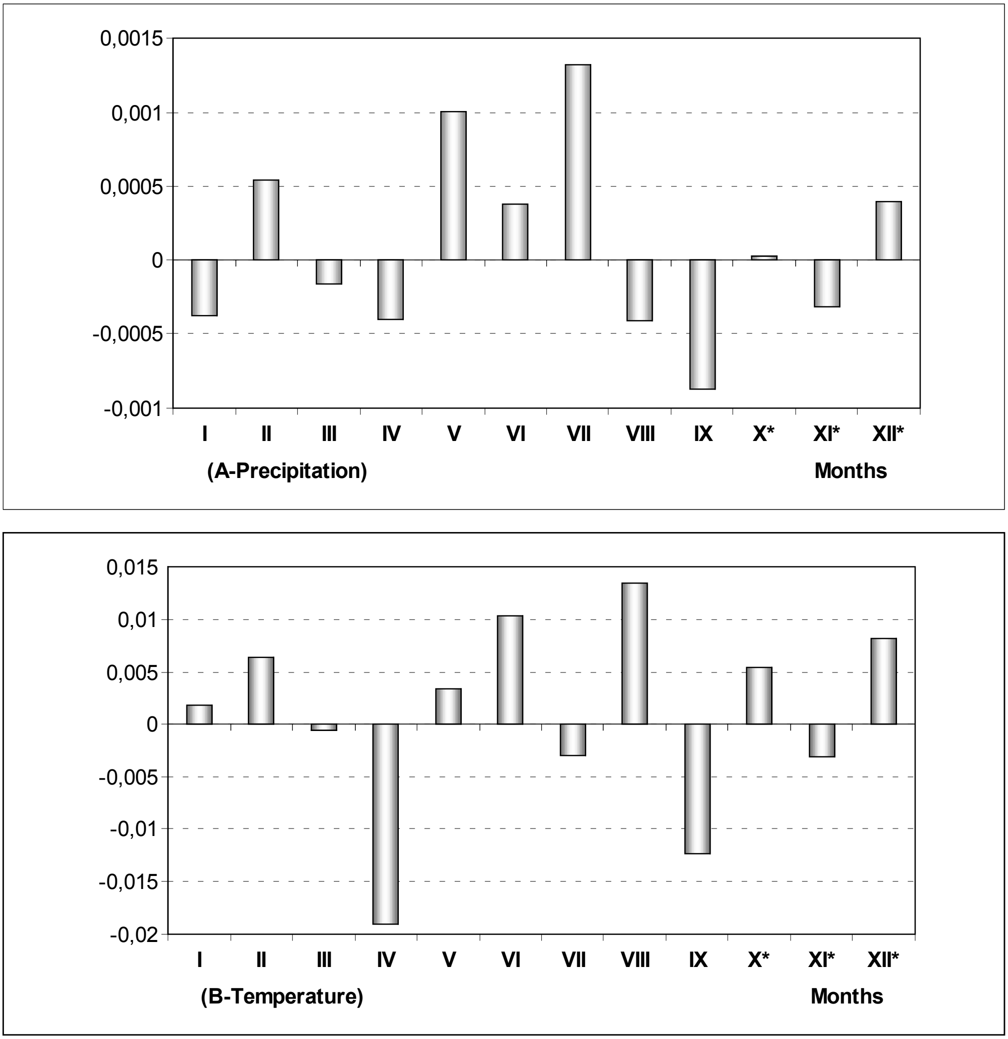

Fig. 6. Climate-growth relationships (regression coefficients) of Oak trees calculated by response function analyses.

Remark: the months with stars in response functions are for previous year.

tions in the period May–July on the indices for the tree-ring growth.

Conclusion

Scots pine forests in the study area have passed through 5 major stress periods during the 20th century. Only two of these periods were reflected in the Oak chronology – from the beginning of 1940s to the end of 1950s and from the beginning of 1980s to the middle of 1990s. At the beginning of the current 21st century Scots pine trees were again in poor health condition.

No single factor was clearly identified as the cause of forest decline. Among the important predisposing factors were the unfavorable climate conditions and drought in particular. The “climate-growth” relationship was stronger for the Scots pine, as compared to Hungarian oak. Other factors, such as air pollution with O_3, fungal diseases and insect damages have also played part in the forest decline.

The identified factors affect forest health over large areas, wherefore greater international cooperation is needed to solve such a complex environmental issue.

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