Climatic Signal in Earlywood, Latewood and Total Ring Width of Crimean Pine (*Pinus nigra* subsp. *pallasiana*) from Crimean Mountains, Ukraine

IRYNA KOVAL
Laboratory of Forest Ecology, Ukrainian Research Institute of Forestry and Forest Melioration, Pushkinska, 86, Kharkiv, 61024, Ukraine

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Abstract

The influence of climatic factors of the subtropical climate on the growth of *Pinus nigra* subsp. *pallasiana* in 110-year-old stand on the southern slope of the Crimean Mountains of Ukraine was evaluated by comparing earlywood, latewood and total ring indices with monthly temperature and precipitation data for 1973-2011. Two periods (1973-1992 and 1993-2011) were compared to detect features of the response of latewood, earlywood and total rings to climate change.

The following tendency was revealed: increase in the mean annual temperature by 0.3 °C (2.5%), increase in the temperature in April-August by 0.8 °C (4.3%), increase in March temperature by 0,2 °C (4.1%), decrease in winter temperature by 0,4 °C (7.8%) in 1993-2011 in comparison with 1973-1992. Mean annual precipitation increased by 19 mm (1.3%), precipitation in April-August decreased by 46 mm (20%), precipitation in the cold period (from the last November to March) increased by 44 mm (12%). The relative humidity of air reduced by 1% over the year, by 5% in April-August and increased by 5% in winter.

Correlation and analysis of pointer years show that summer drought during 1993-2011 limited the radial growth in Crimean pine more than in 1973-1992. The decrease in winter temperature has also led to an decrease in the radial growth of *Pinus nigra* subsp. *pallasiana* in 1993-2011. Latewood layers appeared to be more sensitive to climate than earlywood rings. Assuming that summer water stress will increase, and winter temperature will decrease, we can expect decline in the radial growth of pine next years.

Key words: Crimean pine, subtropical climate, Crimean Mountains, earlywood, latewood, total ring.

Introduction

Climate change is an important issue today. Since the middle of 1960s, and especially in 1970-1971, a cooling trend in the Northern Hemisphere changed to a warming trend (Парубец 2009). The identification of climate change peculiarities on the southern slope of the Crimean Mountains under conditions of the Mediterranean climate (this area is known as ‘Northern Subtropics’) and peculiarities of the response of tree radial growth to these changes is needed.

Dendrochronological analysis is an indispensable tool to reveal a response of forest stands to environmental changes. The tree ring width, wood density and pointer years provide information on environmental changes for each year in the life of the tree (Битвинскас 1967, Koval 2008, Коваль 2011, Коваль 2012).

To reconstruct climate for Crimean peninsula, Solomina O.M. et al. (2005) have built tree ring chronology for *Pinus hamata* Sosn D. (1620–2002) for the first time. A tree-ring reconstruction of April–July precipitation, spanning AD 1620–2002, has been presented.

Investigation of earlywood and latewood separately gives the possibility to reveal more details on relationships between climate and the radial growth. Study of the effects of climatic factors (i.e. monthly mean temperature and total precipitation) on the radial growth (earlywood width, latewood width, and total ring width) in a pedunculate oak (*Quercus robur* L.) stand in Northeastern Hungary has revealed the weakest common variance and lack of statistically significant relationship to monthly precipitation and temperature for earlywood widths; however, the width of latewood showed the strongest common chronological signal (Kern et al. 2013).

Climate of South Crimea is characterized by dry growing period (mean temperature in July and August is about +23 ºC, mean precipitation for these months is 45 mm) and rather moist cold period (mean precipitation for November – December of previous year and January-February of current year is 64 mm). Most of the precipitation decreases during October-April. Mean temperature in January is about +4 ºC. Mean annual precipitation is 627 mm. Mean annual temperature is 12.8 ºC. Mountains protect the coastal area against dry hot air of the Steppe in summer and from cold northern wind in spring. The Black See tempers the climate. Increasing trend of temperature and precipitation was detected for meteorological station of Aj-Petri for 90-years (Парубец 2009).

The objectives of this research were to study the relationships between climate and earlywood, latewood and total ring width of Crimean pine (*Pinus nigra* subsp. *pallasiana*) and to evaluate the tendencies in local climatic parameters of subtropical part of Crimean peninsula.

Material and Methods

The study area is located on the southern slope of the Main Ridge of Crimean Mountains, which is covered with Crimean pine and oak forests at 500-900 m a.l.s. The soil is mountain-forest brown (Russian classification) (Классификация и диагностика почв СССР 1977).

Study of the radial growth of Crimean pine was performed in a pure 110-year-old pine stand of Gurzuf forestry in the Yalta Mountain Nature Reserve at altitude 460 m a.s.l. on 20° slope. According to the Russian classification, there is 5th Growth (yield) class (Анучин 1982). The growing stock is 320 m^3/ha.

Data for the period 1973-1990 from Yalta meteorological station (44°49'N; 34°15'W) and for the period 1991-2011 from the meteorological station of Nikitsky Botanical Garden (44°30'N; 34°13'W) were used to detect relationships between the tree radial growth and climatic factors (Figure 1).

The standard dendrochronological methods were used. Cores were taken at the height 1.3 m of tree stem from 16 trees of Crimean pine, then samples were air-dried (Битвинскас 1974).

The digital equipment for *measurement* of *tree rings "HENSON*" was used. All cores were dated using visual and graphical techniques. The crossdating quality and measurement accuracy of tree-ring series were statistically assessed by the programme COFECHA (Grissino-Mayer 2001).

To produce chronologies from tree-ring measurement series by detrending and standardization (indexing) the tree ring series, the programme ARSTAN was used (Holmes 1983). The chronologies STANDARD, RESIDUAL and ARSTAN were calculated for earlywood, latewood and total ring width of Crimean pine. Age trends were eliminated from series of measurements when calculating STANDARD-chronology. For growth modelling, a negative exponential curve was fitted to each individual series. Only this version of chronology was calculated without the autoregressive analysis. On the basis of the standardized series, the RESIDUAL chronologies were developed using the autoregressive modelling. The approximation for autoregressive process was obtained separately for each series and the mean value of individual series was calculated. ARSTAN-chronology was calculated by reincorporating the pooled autoregressive into the residual chronology. It was the attempt to capture as much climatic signal as possible (Holmes 1983).

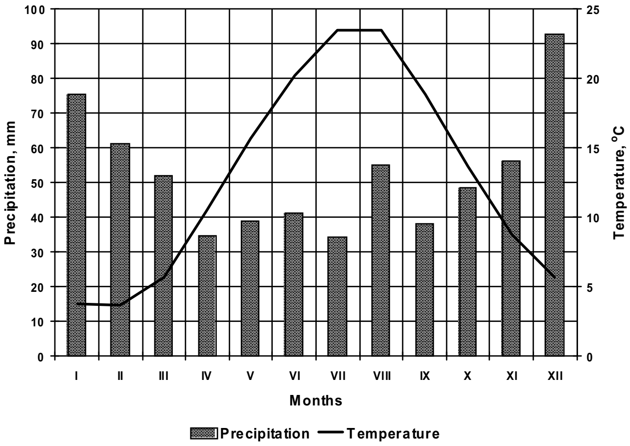


Figure 1. Climatic diagram for Yalta and Nikitsky Botanical Garden

The search for relations between climate and radial growth is usually based on the statistical comparison of the long-term growth-ring chronologies with series of monthly meteorological data, mainly temperature and precipitation for the same period. This approach allows explanation of "average" climate-growth relationships and reveals changes in climate and environment (Schweingruber et al. 1989).

The development of pine stand growth was investigated analyzing curves of the radial growth of latewood width, early width and tree annual width (being measured with accuracy 0.01 mm) and pointer years. Correlation analysis was used to detect relations between climatic factors and index tree ring series of earlywood, latewood and total ring.

Results

Statistical data analysis by the programme COFECHA showed high synchronism for series of earlywood, latewood and total ring width of Crimean pine for 1860-2011 (Table 1).

The standard deviation of tree ring series characterizes the variability of tree radial growth. The first-order autocorrelation demonstrates the level of influence of previous year environmental conditions on tree ring width of current year. Minimum values of the standard deviation and the first-order autocorrelation were found for late wood. The highest index of sensitivity indicates that the latewood has the highest sensitivity to environmental change (Table 1).

Table 1. Descriptive statistics for series of late-, earlywood and total ring width of Crimean pine in the stand on southern slope of Crimean Mountains

	Mean width, mm	Correlation coefficient between tree ring series	Standard deviation	First order auto-correlation	Mean sensitivity
Latewood	0.49	0.511	0.347	0.667	0.448
Earlywood	0.75	0.434	0.459	0.703	0.284
Total ring	1.23	0.505	0.730	0.752	0.285

The years of minimum growth are 1902, 1921, 1942, 1976 and 1994. These years were characterized by unfavourable weather conditions for pine. After these years, release of pine radial growth was observed. Mortality in small trees in the stand probably was the cause of improvement of lighting and nutrition for roots of living trees. The rapid increase in the growth of all wood layers in Crimean pine resulted from this influence in 1903-1912 and 1922-1969. Periods of trend of the rapid decline in the radial growth are as follows: 1860-1902, 1913-1921, from 1970 – to the present. A rapid decrease in tree radial growth was observed particularly in 2000-2011 (Figure 1).

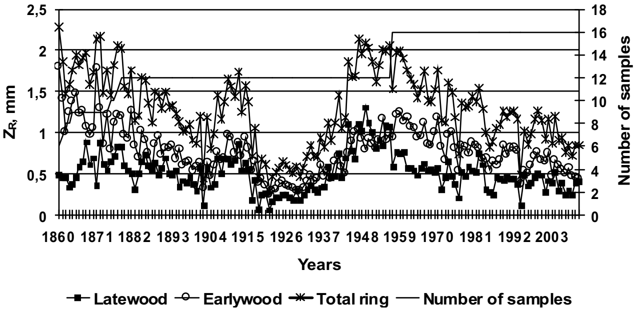


Figure 2. Dynamics of late-, earlywood and total ring widths of Crimean pine on southern slope of Crimean Mountains and number of samples (secondary axis)

A comparison of meteorological data for 1973-1992 and 1993-2011 has detected the following tendency: in 1993-2011 an average annual temperature has risen by 0.3 °C (2.5%) and by 0.8 °C (4.3%) in April-August in comparison with previous 1973-1992. At the same time, winters have become colder (winter temperature has decreased by 0.4 °C (7.8%) and early spring (March) temperature has decreased by 0.2 °C (4.1%) (Figure 3).

Annual precipitation in 1992-2011 has increased by 19 mm (1.3%), precipitation has decreased by 46 mm (20%) in April-August, and precipitation has increased by 43 mm (14%) in the cold period (from the last November to March) in comparison with previous period (1973-1992) (Figure 4).

In 1992-2011 the relative air humidity has decreased by 1% over the year, by 5% in April-August and by 5% in winter in comparison with previous period (1973-1992) (Figure 5).

The positive significant correlations were detected between the index series of early wood and precipitation for the first part of study period (1973-1992). For the second part of the study period (1993-2011) almost all correlations have lost significance (Table 3). Notable decrease in precipitation during growing period in 1993-2011 negatively influenced earlywood formation.

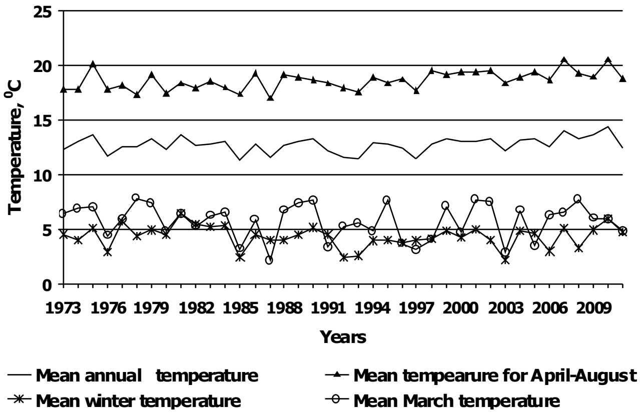


Figure 3. Dynamics of air temperature (data for Yalta meteorological station used for 1973-1990 and data for the Nikitsky Botanical Garden station used for 1991-2011)

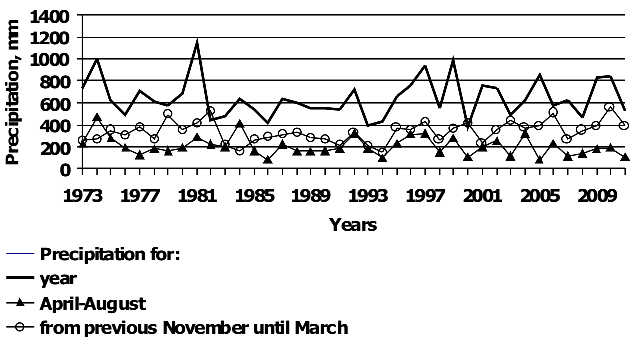
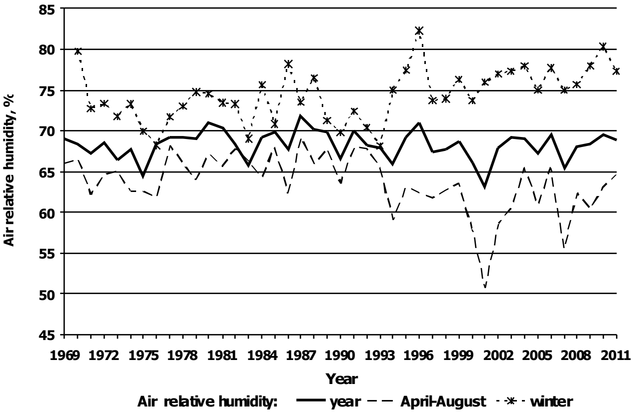


Figure 4. Dynamics of precipitation (the Nikitsky Botanical garden and Yalta meteorological stations)



Fugure 5. The dynamics of relative air humidity (the Nikitsky Botanical Garden and Yalta meteorological stations)

The correlation analysis between indices of tree ring series of late-, earlywood, total ring and climatic factors is shown in the Table 2.

The causes of radial growth depressions in Crimean pine are shown in Table 3. Last years (1994, 2003, 2005 and 2007) of minimum radial growth were characterized by the minimum precipitation for April-August that has decreased by 37-56% in comparison with the average. During this year, the pine radial growth has decreased by 30-62% in comparison with mean value.

Last years (1994, 2003, 2005 and 2007) with the minimum radial growth are characterized by minimum precipitation for April-August that has decreased by 37-56% in comparison with the average. During these years, the radial growth in Crimean pine has decreased by 30-62% in comparison with mean value.

Solomina O.M. et al. (2005) developed *Pinus hamata* Sosn D. chronology (1620–2002) from Aj-Petri, Crimea for the first verifiable dendroclimatic reconstruction for this region. This chronology showed the strongest relationship with April-July precipitation at Aj-Petri ($r = 0.61$; $p = 0.01$) over 1896–1988. The negative correlations with growing season temperatures, especially from July–September, were found. On the contrary, correlations of the positive winter spring temperature indicate that warm winters and springs are favorable to the formation of wide tree rings.

Table 2. Correlations between tree ring index series of earlywood, latewood, annual rings and climatic factors for Crimean pine stand on southern slope of Crimean Mountains

	S^{+}		R^{++}		A^{+++}	
	Early wood					
Climatic factors	1973-1992	1993-2011	1973-1992	1993-2011	1973-1992	1993-2011
Annual precipitation, mm	0.48*	-0.12	0.40	0.29	0.47*	0.01
Precipitation for III-X months, mm	0.63**	0.29	0.48*	0.45	0.65**	0.26
	Late wood					
Average winter temperature, mm	0.50*	-0.02	0.30	-0.03	0.48*	-0.01
Average annual relative humidity, %	-0.09	0.45	0.10	0.68**	-0.07	0.41
Average relative humidity for IV-VIII months	0.32	0.52	0.50	0.64**	0.38	0.47*
	Total rings					
Average winter temperature, °C	0.45*	0.02	0.33	0,12	0.45*	0.04
Precipitation for IV-VIII months, mm	0.32	0.37	-0.09	0.54*	0.29	0.36
Average annual relative humidity, %	-0.07	0.23	0.22	0.51*	-0.05	0.19
Average relative humidity for IV-VIII months	0.27	0.34	0.55*	0.57**	0.37	0.30

S^{+} – STANDARD tree ring index chronology; R^{++} – RESIDUAL tree ring index chronology; A^{+++}– ARSTAN tree ring index chronology; * – Correlation is significant at the 0.05 level; ** – Correlation is significant at the 0.01 level.

The significant positive correlation between winter temperature and tree ring index series of latewood and total growth rings for 1973-1992 was detected; however, there are no significant correlations for the following period 1993-2011. It is probably related to a decrease in winter temperature during the second period.

The relative humidity of air is cumulative parameter that reflects the ratio of temperature to precipitation. Significant positive correlations between the relative humidity of air during the year, different parts of growing period and indices of latewood and annual growth rings were revealed for 1993-2011. It indicates the increase in negative effect of the rate of temperature and precipitation on the formation of annual ring and a ring of latewood.

The significant correlations between the annual tree ring indices and precipitation for growing period during the second part of the study period were found.

N. Kose et al. (2012) identified the most important climate factors affecting radial growth in black pine (*Pinus nigra* Arn. subsp. *Pallasiana)* in western Anatolia and classified its responses to climate. The results suggest that the major limiting factor is drought caused by the low precipitation, especially in May. Black pine trees respond positively to higher temperature at the beginning of growing season.

Levanic et al. (2013) detected the rise in the temperature and decrease in the precipitation pose a major future challenge for sustainable ecosystem management in Romania. To understand ecosystem response to environmental change, a 396-year long (1615-2010) drought sensitive tree-ring width chronology of *Pinus*

Table 3. Pointer negative years of Crimean pine radial growth in the stand on southern slope of Crimean Mountains

Year of minimum growth	Reasons caused radial growth depression in Crimean pine
1875, 1882, 1887, 1900, 1902, 1911, 1916, 1921, 1937, 1942, 1952	Reasons of the tree radial growth depressions are unknown due to absence of weather data. In early spring of 1942 due to military operations of the Second World War, damage of trees in stand grow-ing on mountain Aj-Petri were occured that provoke the pine radial growth depression (Максимовский 2006).
1971	During April-August, precipitation decreased by 41% in comparison with the average volume.
1972	Temperature for April-June increased by 12%, for April-August by 9% in comparison with the average volume.
1976	Precipitation for April-August decreased by 37% in comparison with the average volume. Winter temperature decreased by 34% in comparison with the average volume.
1990	Precipitation for April-August decreased by 43% in comparison with the average volume.
1994	Precipitation for April-August decreased by 51% in comparison with the average volume.
2003	Precipitation for April-August decreased by 46% in compareson with the average volume. In addition, March temperature decreased by 50% in compareson with the average volume.
2005	Precipitation for April-August decreased by 37% in compareson with the average volume.
2007	Precipitation for April-August decreased by 56% in compareson with the average volume.

nigra var. *banatica* growing on steep slopes under conditions of a continental climate affected by Sub-Mediterranean climate was developed. The quality and the spatial strength of the climate signal in chronology showed the greatest correlation between residual chronology and July precipitation ($0.5>r>0.6$, $p<0.05$) in the region covering the southwestern part of Romania, north-western part of Bulgaria and eastern part of Serbia, which corresponds to the vicinity of the sampling location. A slightly lower spatial correlation ($0.4>r>0.5$, $p<0.05$) can be observed in the most part of the Balkan Peninsula. Authors identified July precipitation as the most important factor influencing *Pinus nigra* growth on the studied site ($r = 0.54$, $p<0.01$). Correlation analysis for the period spanning from the previous September to the current September showed that July is almost twice as important for tree ring formation as the next most significant month, June. Since the site is very extreme with respect to the lack of precipitation, it has an important role in the tree growth, as above-average precipitation in July promotes tree growth and significantly affects tree-ring width.

Comparison of links of all tree ring chronologies of *Pinus hamata* and *Pinus nigra* with climate variability showed that droughts during growing period significantly limited formation of tree rings. Droughts in April - July most affect the tree growth. Positive correlations in spring-early summer are typical for chronologies of Mediterranean climates (Hughes et al. 2001) and reflect the importance of moisture supply during this period of active growth.

Conclusions

Subtropical climate of the south part of Crimean peninsula is characterized by decreasing precipitation and warming during vegetation period, decreasing winter temperature in 1973-1992 as well as an increase in mean annual temperature.

Cold winters, low temperature during early spring and droughts in growing periods are limiting factors of the radial growth of Crimean pine.

Investigation of relations between tree radial growth and climatic factors in 1973-1992 and 1993-2011 shows the positive effect of warm winters on the late and annual layers of Crimean pine in 1973-1992. The following 1993-2011 winters have become colder and positive effect on the radial growth was lost. The increase in temperature and decrease in precipitation during growing period negatively affected the formation of early, late and annual wood in 1993-2011. Effect of the increase in relative air humidity on the formation of the late and annual wood was detected in 1993-2011. Latewood has the highest sensitivity to change in environment.

The radial growth of pine will probably decline in the next years, assuming that the rise in temperature and decrease in precipitation during growing period and decrease in winter temperature will continue.

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КЛИМАТИЧЕСКИЕ СИГНАЛЫ В РАННЕЙ, ПОЗДНЕЙ И ГОДИЧНОЙ ШИРИНЕ КОЛЬЦА СОСНЫ КРЫМСКОЙ (*PINUS NIGRA* SUBSP. *PALLASIANA*) В КРЫМСКИХ ГОРАХ, УКРАИНА

И. Коваль

Резюме

Влияние климатических факторов на прирост сосны крымской, растущей в 110-летнем насаждении в условиях субтропического климата на южном склоне Крымских гор оценивали путем сопоставления индексов ранней, поздней и годовой древесины с показателями температур и осадков за 1973-2011 гг. Сравнили два периода: 1973-1992 и 1993-2011 гг., чтобы определить особенности реакции прироста поздней, ранней и годовой древесины на изменения климата

Была выявлена следующая тенденция: в 1993-2011 гг. при сравнении с предыдущими 1973-1992 гг. средняя годовая температура возросла на 0,3°C (2,5%), температура за апрель-август – на 0,8°C (4,3%), за март – на 0,2°C (4,1%), за зимний период – уменьшилась на 0,4°C (7,8%). Среднегодовое количество осадков увеличилось на 19 мм (1,3%), за апрель-август уменьшилось на 46 мм (20%), за холодный период (с предыдущего ноября по текущий март) – увеличилось на 44 мм (12%). Среднегодовая относительная влажность воздуха уменьшилась на 1%, за апрель-август – на 5%, за зиму – возросла на 5%.

Корреляционный анализ и анализ реперных лет показал, что радиальный прирост сосны лимитировался летними засухами в 1993-2011 гг. в большей степени, чем в 1973-1992 гг. Зимнее похолодание также негативно повлияло на радиальный прирост деревьев в 1993-2011 гг. Слои поздней древесины оказались более чувствительными к изменениям климата, чем слои ранней древесины. Возможно, радиальный прирост деревьев будет ухудшаться в последующие годы в результате возрастающего летнего водного стресса и снижения зимних температур.

Ключевые слова: сосна крымская, субтропический климат, Крымские горы, слои поздней, ранней и годовой древесины.