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Different growth patterns of *Picea schrenkiana* subsp. *tianshanica* (Rupr.) Bykov and *Juglans regia* L. coexisting under the same ecological conditions in the Sary-Chelek Biosphere Reserve in Kyrgyzstan

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Abstract: The main aim of the study was to compare the radial growth of Persian walnut and Schrenk spruce trees growing under the same ecological conditions in the Sary-Chelek range of the Tien-Shan Mountains, as well as to analyse the response of these species to the selected climate factors in line with the altitude gradient. Four study plots were established at the altitude of 1350, 1400, 1450 and 1500 m a.s.l. Results indicated that (1) walnut and spruce in the Sary-Chelek Biosphere Reserve have different patterns of radial increment and reaction to climate factors, despite growing in the same habitat, (2) spruce radial growth responded to low precipitation and low temperature during the April to September period of the previous year; (3) walnut radial increment patterns varied significantly with changes in altitude, whereas spruce patterns did not; and (4) walnut radial increment patterns responded positively to high temperature during contemporary growing season and to precipitation during the prior growing season. In addition, it was noted that precipitation during the contemporary growing season could negatively influence growth.

Additional key words: dendroecology, Kyrgyzstan, Persian walnut, Schrenk spruce, Sary-Chelek Biosphere Reserve

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Introduction

Kyrgyz forests are characterized by significant dispersion and low coverage (up to 5%). This is caused by the topography of the land, of which 93% is covered by high mountains (Grisa et al. 2008). As a result, there are only a few places, where the forests create dense and multi-species stands. One of the most interesting forests in the country is situated in the southern part of Kyrgyzstan, where in the same habitat many various tree species have found conditions suitable for their existence. Schrenk spruce (*Picea schrenkiana* subsp. *tianshanica* (Rupr.) Bykov) and the Persian walnut (*Juglans regia* L.) are among the main forest forming species in the mountains of southern Kyrgyzstan. This portion of the Tien-Shan Mountains includes the Chatkal range to the north and the Fergana range to the south, together they are referred to as the Fergana-Chatkal region. Shrenk spruce grows only in the Chatkal range, while walnut grows in both the Chatkal and Fergana ranges (Grisa et al. 2008; Gan 1970). The Sary-Chelek Natural Reserve is situated in the Chatkal range and is widely recognized for its unique ecological significance, having been designated as a UNESCO Biosphere Reserve (Grisa et al. 2008). Some species growing there, including walnut, were entered in the Red Book of Kyrgyzstan (Eastwood et al. 2009).

The first survey of walnut and spruce forests of Kyrgyzstan were conducted by Sukachev (1949) and Gan (1970, 1992). More recently, an inventory and description of Kyrgyz forests was conducted by Grisa et al. (2008). Research of the climate impact on walnut radial increment was accomplished by Friedrichs et al. (2006) and Winter et al. (2009). These studies used material only from the Fergana range. Dendrochronological research on the Schrenk spruce in the Kyrgyz part of Tien-Shan was started by Borsheva (1986) and continued by Maximova and Solomina (2010). This research did not however analyse forests in the Sary-Chelek region of the Chatkal range.

The main goal of the presented study was to assess and quantify radial increment of two main tree species in the Sary-Chelek UNESCO Biosphere Reserve as well as to assess their growth strategies. We presumed that the growth characteristics of the species are entirely different despite of the fact that they grow in the same habitat. Knowledge of the species environmental requirements and life strategies can support the protection of the Reserve, which is an extremely valuable area still intensively utilized by the local community. Our direct objectives were to investigate and compare i) the radial growth of walnut and spruce trees growing in the Sary-Chelek regionof the Chatkal range and ii) response of these species to the selected climate factors.

Material and methods

Study site

The study was conducted in the Sary-Chelek Biosphere Reserve, which is situated on the southern slopes of the Chatkal range in the western part of the Tien-Shan Mountains (Fig. 1). As it has the highest nature protection status, no forest management is conducted there. Compared to forests in southern Kyrgyzstan, the climate in Sary-Chelek is more humid and warm. This is because high mountains surround the Reserve, protecting it from the cold air masses flowing up in from the north. Thus, in the winter the temperature in the Reserve is higher than in the surrounding valleys, and in the summer it is no lower than in other parts of southern Kyrgyzstan. The climate at the Sary-Chelek station (Fig. 2) can be characterized as Db type according to the classi-

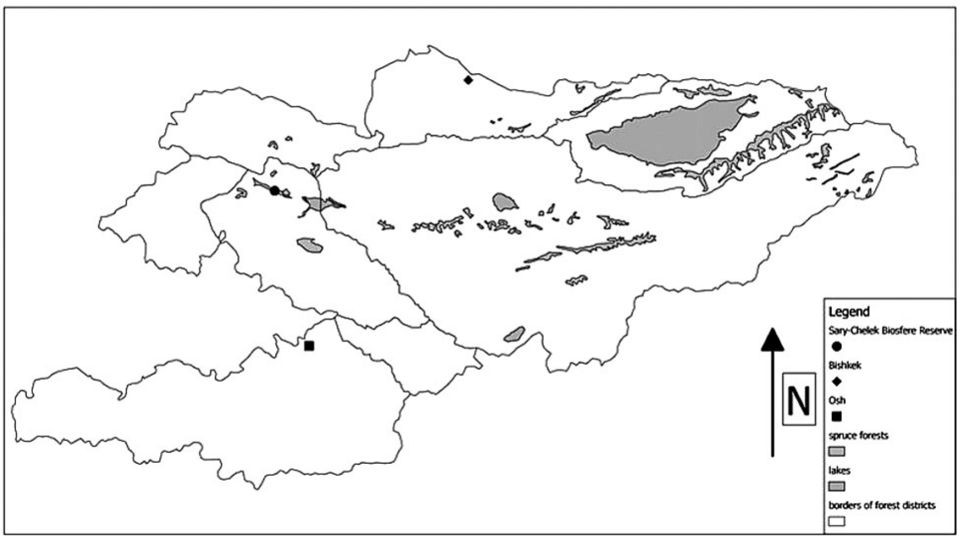

Fig. 1. Map of Kyrgyzstan with Sary-Chelek Biosfere Reserve

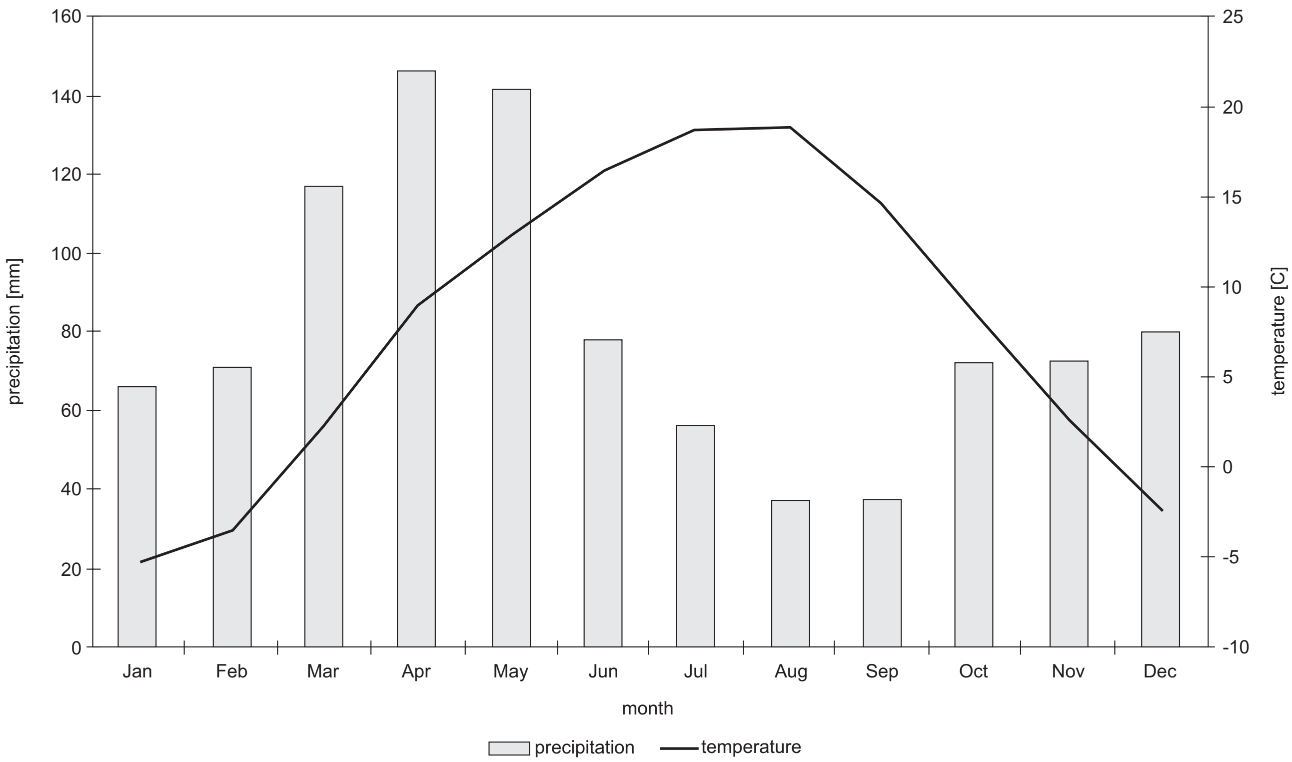

Fig. 2. Mean monthly temperature (1966–2009) and precipitation (1969–2009) for meteo-station in Sary-Chelek village (1100 meters above sea level)

fication by Köppen (Grisa et al. 2008). The average annual temperature is 7.9°C. The hottest month is August with an average temperature of 19°C, while the coldest month is January with an average temperature of –5.3°C. The average annual rainfall is 993 mm, most of which falls from March to May, when the average monthly precipitation is at a level of 120–150 mm. The least rainfall occurs in August and September with an average of 37 mm per month.

Field works and data acquisition

Four study plots (Table 1) were established along the altitude gradient from the altitude 1350 to 1500 m a.s.l. Research material was collected in the spring of 2010. Corers were taken from dominant and co-dominant trees growing under the same habitat conditions. One increment core was taken with a Pressler borer perpendicularly to the slope from each tree located on the plot. This method of sampling was chosen to exclude the effect of slope gradients on the tree ring width in the extracted sample. This is a proper method for mountain conditions because it amplifies (focuses on) the climatic factors (Zielski and Krąpiec 2004). There were 20 to 26 cores collected from each plot, depending on the species and number of trees in the area (Table 1). After preparation in the laboratory, all the cores were scanned with a resolution of 1200 DPI. The tree-ring widths were measured using CooRecorder 7.3 software (www.cy-

Table 1. Characteristics of study plots (S1–S4) and research material taken from Sary-Chelek Biosphere Reserve in Kyrgyzstan

Plots name	S1	S2	S3	S4
Elevation [m a.s.l.]	1350	1400	1450	1500
N	41°46'543"	41°47'669"	41°48'022"	41°48'429"
E	71°57'254"	71°56'915"	71°56'622"	71°58'439"
Slop gradient [°]	45	13	25	40
Exposition/Slope	N	N	N	N
Number of spruce cores	20	25	20	20
Number of analysed spruce cores	18	23	18	18
Mean overall correlation with master spruce chronology	0.66	0.55	0.60	0.61
Number of walnut cores	25	23	26	20
Number of analysed walnut cores	21	15	24	17
Mean overall correlation with master walnut chronology	0.22	0.20	0.35	0.13

Table 2. The descriptive statistics of spruce and walnut standard chronologies from the study plots

	Spruce				Walnut			
	S1	S2	S3	S4	S1	S2	S3	S4
Mean dbh (cm) diameter of the breast hight	33.7	36.7	49.1	42.9	40.4	45.1	45.9	43.9
Mean height (m)	21.1	26.5	24.6	26.8	12.5	14	14.7	13.3
Quantities tree per 0,25 ha	44	54	29	42	23	28	16	21
Chronology length	1906–2009	1834–2009	1887–2009	1821–2009	1852–2009	1796–2009	1855–2009	1868–2009
Mean tree rings width index	0.94	1.01	0.95	1.00	0.95	0.92	0.96	0.98
Max tree rings width index	1.50	1.90	1.70	1.52	2.77	2.52	1.55	1.69
Min tree rings width index	0.24	0.19	0.40	0.56	0.21	0.28	0.30	0.32
Median tree rings width index	0.94	0.96	0.93	0.99	0.92	0.93	0.97	0.96
Mean sensitivity for standard chronology	0.185	0.179	0.162	0.147	0.160	0.214	0.167	0.141
Mean sensitivity for residual chronology	0.192	0.212	0.185	0.176	0.188	0.138	0.166	0.172
Standard deviation of tree rings width indices	0.24	0.310	0.28	0.23	0.34	0.35	0.28	0.19
Coefficient of tree rings width indices variability	26%	31%	29%	23%	36%	37%	29%	19%

bis.se). Accuracy of the measurements was verified using CDdendro 7.3 (www.cybis.se).

Analyses

Dendrochronological analysis was conducted according to the standard procedures (Holmes 1994) using the DPL (Dendrochronology Program Library) suite of programs from the Laboratory of Tree-Ring Research, University of Arizona, Tucson, Arizona USA. To exclude samples with low cross-correlation to the other tree-ring width series, additional analysis was performed using the COFECHA program (Holmes 1983). After rejecting the outliers in terms of the similarity of growth (Table 1), ARSTAN software was used (Cook and Holmes 1986; Cook

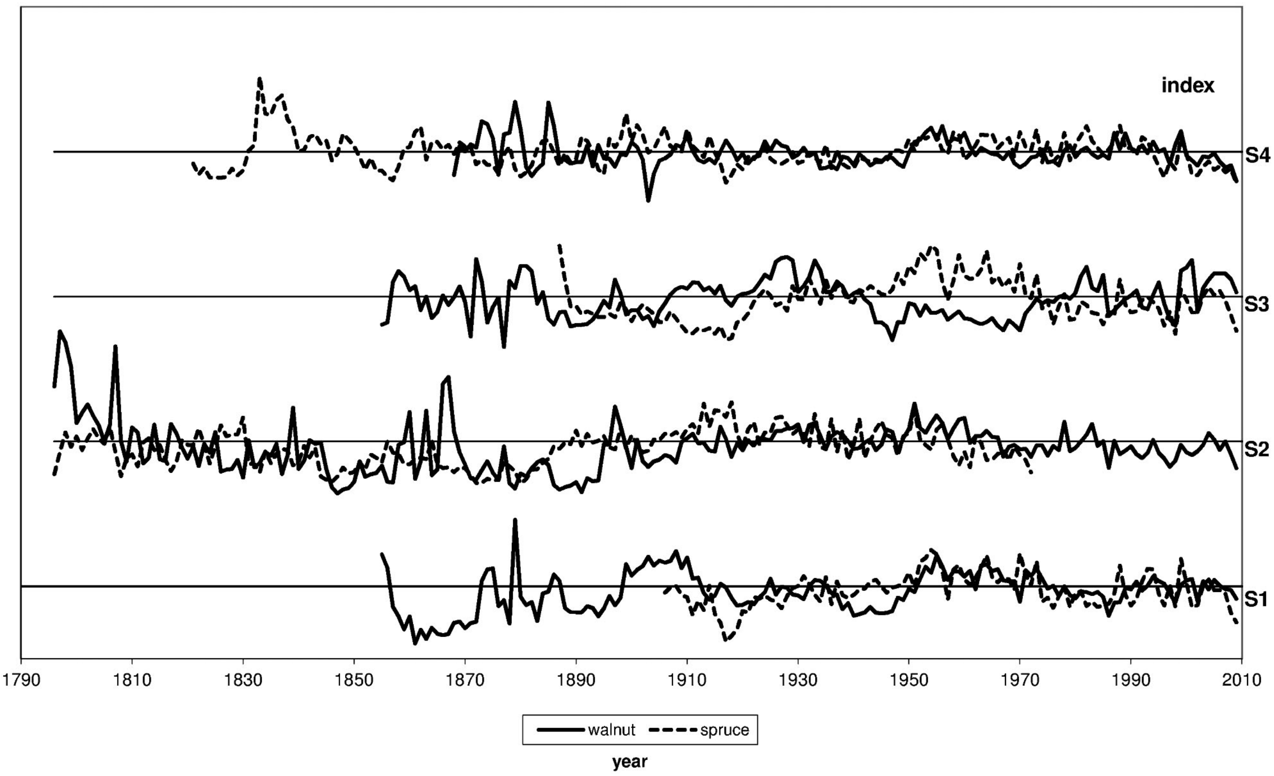

Fig. 3. Standard chronologies for Schrenk spruce and Persian walnut from the study plots in the Sary Chelek Biosphere Reserve

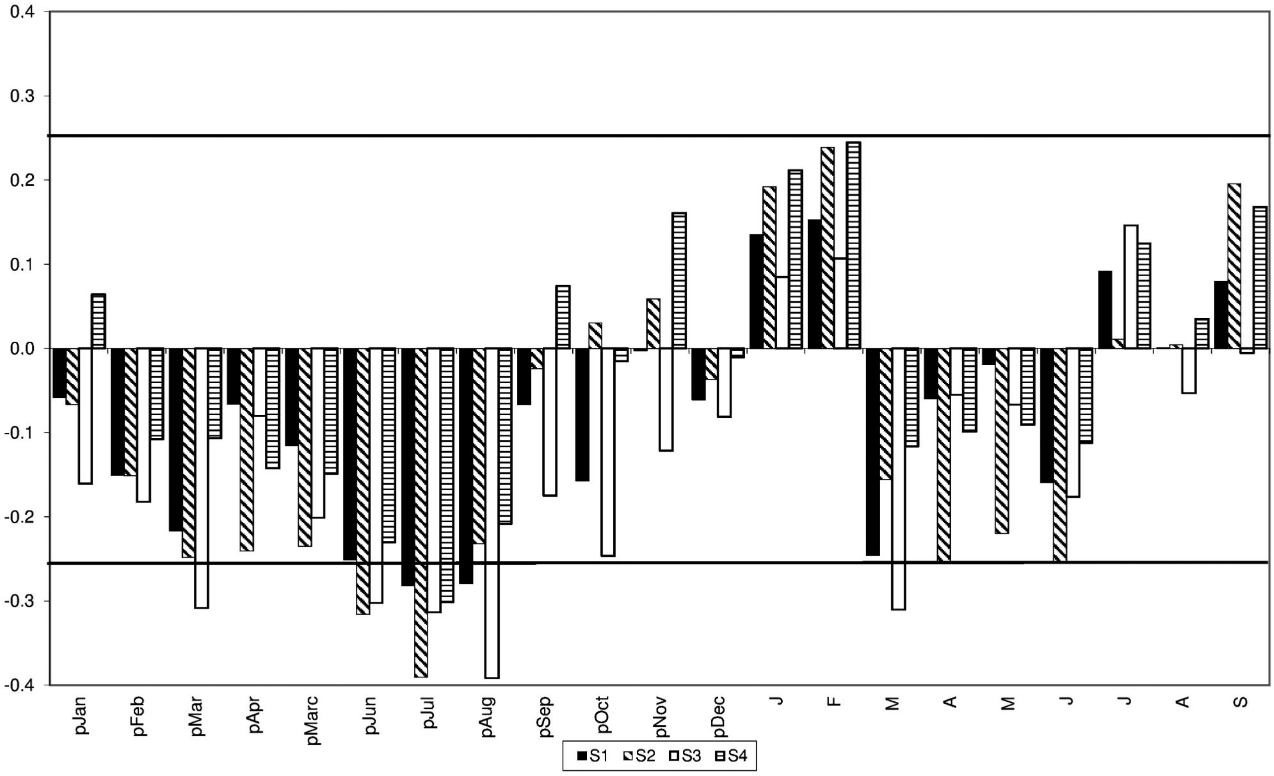

Fig. 4. Person correlation coefficients between residual chronologies of Schrenk spruce and mean monthly temperature (dashed lines indicate 0.05 significance level, p indicates month of the previous year)

and Kairiukstis 1990) to create tree ring width (raw data) and residual chronologies. Tree ring width chronologies were used for the comparison of the radial increment of both spruce and walnut in the analysed area. The following basic statistical measures were calculated: the arithmetic mean, maximum, minimum, median, standard deviation, coefficient of variation and mean sensitivity. The GL (Gleichlaufigkeit) coefficient was also calculated for

Table 3. Similarity (values of GL coefficient) of chronologies from different altitudes (study plots) between and within analysed species

	S1	S2	S3	S4
		spruce		
S1	×	75%	78%	72%
S2	75%	×	76%	74%
S3	78%	76%	×	70%
S4	72%	74%	70%	×
		juglans/walnut		
S1	×	55%	53%	57%
S2	55%	×	58%	60%
S3	53%	58%	×	51%
S4	57%	60%	51%	×
		spruce-walnut		
S1	48%	×	×	×
S2	×	55%	×	×
S3	×	×	50%	×
S4	×	×	×	56%

walnut and spruce chronologies from the analysed area (Eckstein and Bauch 1969). This is assumed that chronologies having the GL value above 65% can be treated as similar to each other at the $\alpha=0.05$ significance level.

Climatic conditions in the Sary-Chelek Reserve were characterized by the average monthly air temperature and total precipitation obtained from the meteorological station situated in the centre of the Sary-Chelek village (500 m distance from study plots, 1100 m a.s.l, temperature time span: 1966–2009, precipitation time span: 1969–2009). Data for the analysis covered both the year of the tree-ring formation and the previous year (a total of 21 months). For each study plot Pearson correlation coefficients were calculated for climate data from the residual chronology. The significance of the observed relationships was recognized at $\alpha=0.05$ level.

In addition, pointer years were determined. Given year was recognized as a pointer year when significant one way changes in growth were observed for at least 80% of individual trees with a minimum of 10 sampled trees (Elling 1966; Huber 1970). The comparison of the determined pointer years allowed for the recognition if trees growing at given locations reacted in the similar way to the extreme climatic conditions.

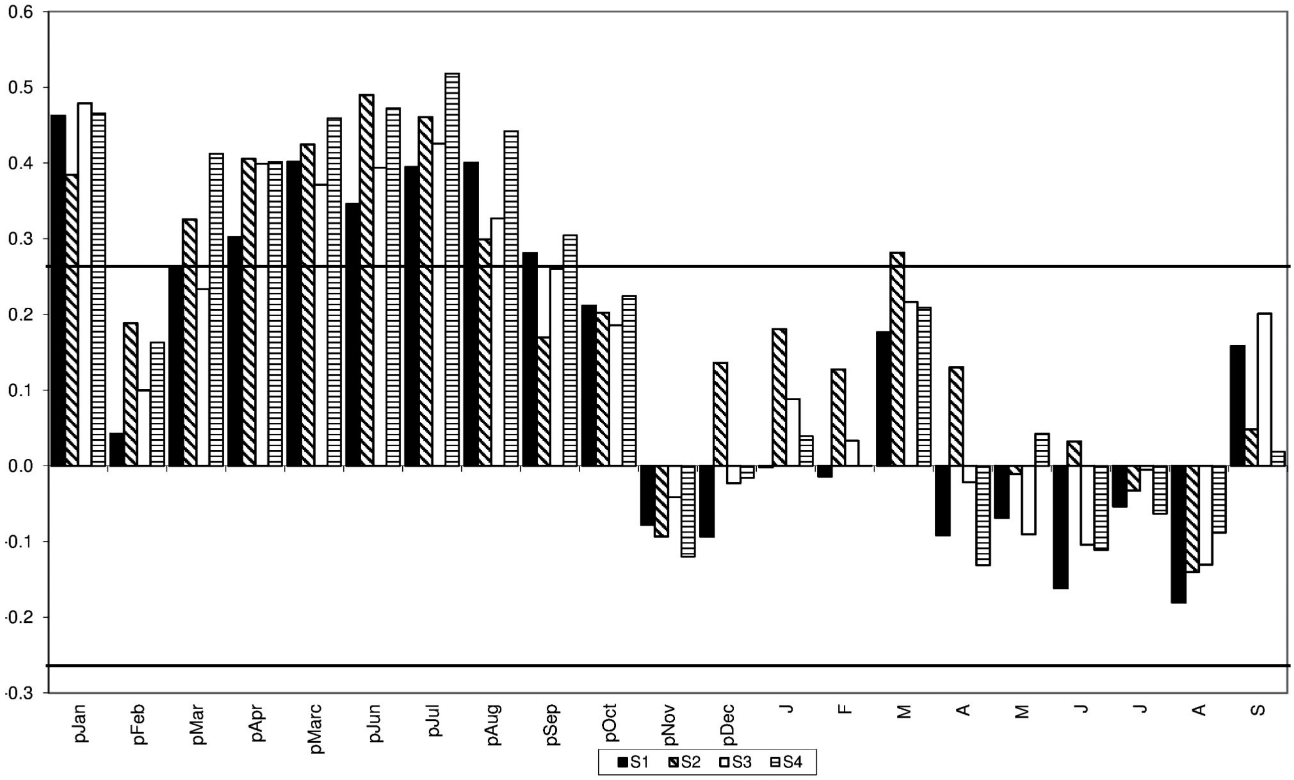

Fig. 5. Person correlation coefficients between residual chronologies of Schrenk spruce and mean monthly precipitation (dashed lines indicate 0.05 significance level, p indicates month of the previous year)

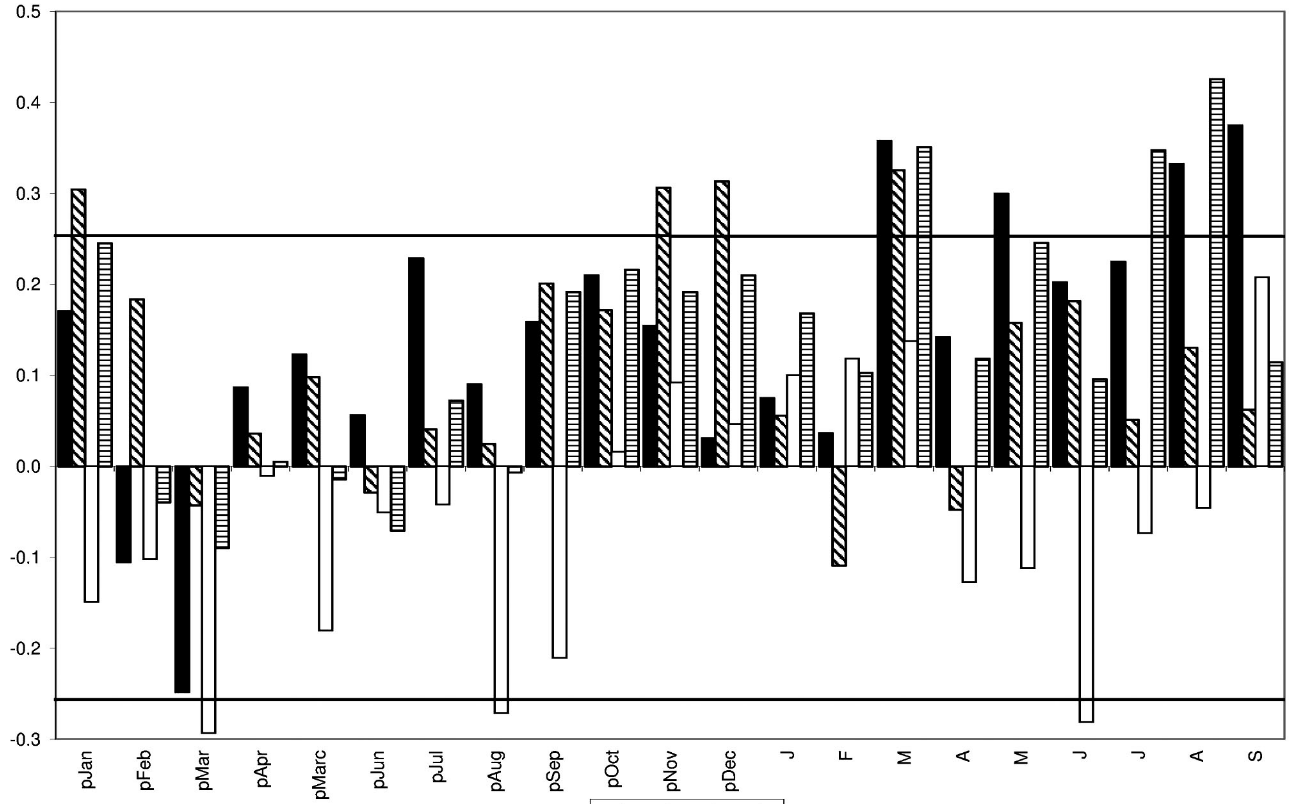

Fig. 6. Person correlation coefficients between residual chronologies of Persian walnut and mean monthly temperature (dashed lines indicate 0.05 significance level, p indicates month of the previous year)

Results

The longest Schrenk spruce chronology spanned the period for 1821 to 2009, while walnut one from 1796 to 2009 (Table 2, Fig. 3). The GL ratio between spruce and walnut chronologies from the same plot ranges from 48% to 56% indicating week similarity of growth patterns of these species. Between walnut chronologies the GL values equaled 51–60%, showing great variability of radial growth of this species. There is greater resemblance in the individual chronologies of spruce as GL ranges from 70 to 76% (Table 3).

The influence of temperature in the year of tree ring formation on the Schrenk spruce tree rings was statistically insignificant (Fig. 4). Significant and positive correlation between the tree ring width and the amount of precipitation was only observed for the period from April to August of the year preceding the ring formation (Fig. 5). This difference however was present on all plots regardless of altitude. A negative relationship between growth and temperature was found on all plots in July in the year of ring formation.

The radial increment of walnut depends significantly on the temperature during the year of tree ring formation (Fig. 6). This relationship is particularly obvious on plot S2, where this dependence is reflected in March, August and September in the year of the tree rings formation and June, November and December from the year preceding the ring formation, and on plot S1 with the significant influence of temperature in March, May August and September in the year of tree rings formation. Pluvial conditions in June, July and August of the year prior to the growth only had a visible effect on S2 plot. In the year of tree ring formation the significant effect of rainfall that fell in January, July was observed on the S3 plot. Incidentally, there is a significant negative correlation from the May of the previous year on S4 plot (Fig. 7).

There were few pointer years detected overall for the analysed species, however positive pointer years for spruce were present at all research plots, namely 1970, 1977, 1988 and 1999. In the case of walnut, there were no common positive pointer years determined at any of the sites. On the S1 plots for example positive pointer years occurred in 1955, on S3 in 1995 and 2000, while on S4 only 1900. The negative pointer years for spruce included 1971, 1974, 1976 and 1979. In terms of walnut, conspicuously narrower rings occurred on plot S3 in the years 1947, 1997, 1998 and 2002, while on S2, in 1903. There were no pointer years which were common for both species.

Discussion

Despite growing in the same habitat conditions, both walnut and spruce exhibit different patterns of

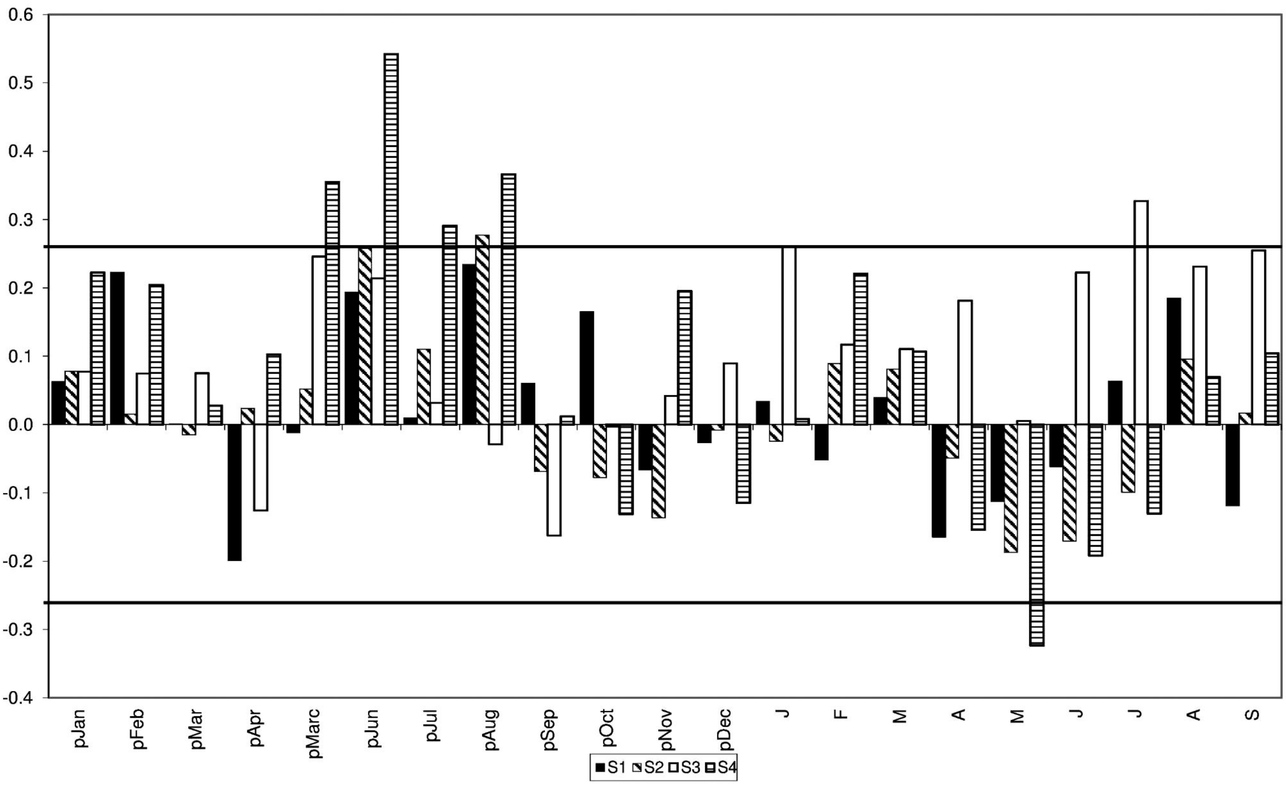

Fig. 7. Person correlation coefficients between residual chronologies of Persian walnut and mean monthly precipitation (dashed lines indicate 0.05 significance level, p indicates month of the previous year)

radial increment over time. These differences occur regardless of the elevation of the site. The values of GL coefficient for walnut chronologies are rather small, which proves the low chronologies conformity of this species. Such low similarity within the walnut series could be caused by the specifics of this species growth on the micro-site, which result in growth of trees from individual sites as if they were different species.

The growth of the Schrenk spruce from the Sary-Chelek Reserve is more dependent on rainfall than on temperature and this pattern occurs at all the analysed plots. Across the entire elevation gradient, the precipitation from the previous year had a positive impact on the tree ring formation This supports suggestions that *Picea Schrenkaina* is one of hygrophilous trees (Zhang and Tang 1989; Wang at al. 2005). Climatic conditions during the year of tree ring formation has little effect on this process. Altitude does not seem to affect the climate-growth relationship among the surveyed trees either. The chosen altitude interval however, might be too small to detect a meaningful difference. The negative influence of temperature on the tree radial increment for spruce was observed on all the research plots. It applies especially to the spring and summer months in the year preceding the tree ring formation. The negative influence of temperature is clearly visible for the summer months (June-August period), when the lowest precipitation and high temperature is observed in the Sary-Chelek Reserve. Such conditions can cause the decreased production of sugars, necessary for the increment in the next year (LaMarche 1974). Worth mentioning is a negative correlation of the radial increment with the temperature in March of the previous year in the S3 plot (1450 m a.s.l.), characterized by high precipitation and low temperature (about 3°C; Fig. 2). This phenomenon can be caused by a snow cover still existing in the area during early spring months. Melting snow together with additional significant precipitation provide too much water as compared to the species requirements. Additionally, relatively flat slope (about 25 degrees) can cause retaining of a large amount of water in place and an extensive soil saturation. During the analysis of the impact of thermal conditions on the growth of walnut stands with elevations above sea level it was observed that walnut forests from plots S1, S2 and S4 showed a positive relationship between the thermal conditions in the year of formation and the tree ring width (March, May, August and September in general). It supports the thesis that walnut requires large amount of warmth (high temperature), while the increment of spruce is driven mostly by the precipitation.

Reaction of walnut radial increment to precipitation was of a different character on distinct plots. A significant influence of the previous year summer precipitation (when the rainfall is the lowest) was observed on the S4 plot (1400 m a.s.l.). This can be explained by the fast water outflow caused by fast melting of snow and steep slope. Thus, in the warmest months trees can suffer from the lack of moisture. There was also a negative influence of precipitation in May and December of the current year observed on the S4 plot. In May this can be caused by the extensive soil saturation due to the melting snow and an additional rainfall. In December the limiting factor can be low temperature, which together with high precipitation can further constrain tree radial increment in the next vegetation season. The above analyses clearly show that the two analysed tree species growing in the same conditions have entirely different strategies of the radial growth.

The result of this positive influence of thermal conditions (main year temperature) on the formation of walnut tree rings agrees with the proposition by Winter et al. (2009); that walnut species are members of the thermophyllous group, which require a large amount of heat during the growth season. According to studies by Winter et al. (2009) from the region of Kara Alma and Arslanbob, a warm spring and early summer results in the optimum level of photosynthetic activity that can positively influence growth.

In plot S3 there was a positive correlation between the previous year's rainfall in January and August and walnut tree ring growth. Similarly, Winter et al. (2009) found a positive correlation between rainfall in the previous summer (July and August) and the previous winter (November and December). Data from plot S4 however, showed a negative correlation between the tree ring growth and the rainfall in the previous summer (June, July, August), which may have been due to the non-specific growing conditions in Central Asia.

Walnut species need high temperatures and large quantities of water to grow. Because temperatures peak in the summer, precipitation during the summer months becomes a limiting factor on growth as indicated by the positive relationship between summer precipitation and growth. According to Gan (1992), the best growth conditions for walnut trees should be present in sample plots located from 1350 to 1400 m a.s.l. This fact was detected by Gan (1970, 1992) and confirmed in this study. The highest values of tree ring width were observed on plots located at an elevation of 1450 m a.s.l (0.96) and at 1500 m a.s.l (0.98) (Table 2). In the case of spruce, there was a positive correlation between the width of the annual tree ring growth and the amount of precipitation from April to September of the year preceding the formation of growth, whilst there was a negative correlation between temperature and growth during this period. Spruce is a hygrophilous species (Zhang and Tang 1989), therefore sufficient precipitation is required for this species to accumulate the necessary organic substances for the next growing season. Thus, rainfall from the previous year correlates positively with growth in the current year. This growth pattern and survival strategy was observed by Wang et al. (2005) with Schrenk spruce growing in the Xinjiang Uygur autonomous region of China.

The pointer year analysis revealed differences between the investigated species. In the case of the Persian walnut, our findings show some confirmation of studies carried out by Friedrichs et al. (2006) in the Fergana range, which is located south of the Sary-Chelek Biosphere Reserve. Two positive years (1995 and 2000) and a negative one (1947) from S3 plot were detected in both places (Winter at al. 2009) also found a few pointer years in the studies carried out in the Fergana range. In that study, negative pointer years of 1998 and 2000 (both from S3 plot) were similar. As far as the Schrenk spruce is concerned, the response to extreme growth conditions is more coherent than in the case of walnut as the number of pointer years that coincide between the plots is higher. When comparing the analysed species, it is obvious that they do not have a common growth signal even in cases of extreme events that could influence their growth.

Conclusions

1. As assumed in the research hypothesis, walnut and spruce species in the Sary-Chelek Biosphere Reserve have different patterns of radial increment and reaction to climate factors, despite growing in the same habitat.
2. Walnut radial increment patterns varied significantly with changes in altitude, whereas spruce patterns did not.
3. Spruce growth negatively responds to low precipitation and low temperature during April to September of the previous year period.
4. Walnut radial increment patterns responded positively to high temperatures during growing season and to precipitation during the prior growing season. In addition it was noted that precipitation during the growing season could negatively influence growth.
5. The pointer years assessed at various plots were generally overlapping, but more common pointer years were noted for spruce than for walnut.

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The study described in this article orginated from † Almazbek Anarbekowicz Orozumbekow. He died at the age of 42 before the publication of this paper, taking with him a lot of unrealized ideas.

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