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CLIMATIC ANALYSIS OF POINTER YEARS IN TREE-RING CHRONOLOGIES FROM NORTHERN IRAN AND NEIGHBORING HIGH MOUNTAIN AREAS

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ZUSAMMENFASSUNG

Der Baumwacholder *Juniperus polycarpos* ist eine weit verbreitete Art an der oberen Baumgrenze der nordiranischen Gebirge. Korrelationsanalysen zwischen indizierten Jahrringchronologien und lokalen Klimadaten deuten an, dass die Jahrringbreite positiv beeinflusst wird durch hohe Niederschläge während des Frühjahrs und Frühsommers sowie durch milde Temperaturen im Dezember vor der Wuchsperiode. Weiserjahre besonders geringen und kräftigen Baumwachstums während des 20. Jahrhunderts wurden mit Hilfe der Cropper-Methode bestimmt. Die räumliche Verteilung und die klimatologischen Ursachen dieser Weiserjahre wurden innerhalb eines Jahrringnetzwerkes untersucht, das 15 Hochlagenstandorte innerhalb der Türkei, Irans, Südrusslands, Kirgistans, Pakistans, Nepals und des tibetischen Hochlands umfasst. Die Wachstumsreaktionen der nordiranischen Standorte ähneln denen in den asiatischen Gebirgsregionen stärker als denen im östlichen Mediterranraum. Negative Weiserjahre mit weiter Verbreitung (1913, 1917, 1951, 1961, 1975, 1991) sind innerhalb des Untersuchungsgebietes häufiger als positive Weiserjahre (1940, 1981). Die klimatische Analyse der Weiserjahre und ihr Zusammenhang mit bestimmten atmosphärischen Zirkulationsmustern kann eine Basis für die Interpretation ähnlicher Verbreitungsmuster von Weiserjahren in der Vergangenheit bieten.

Schlüsselbegriffe: Elburz Gebirge, Kleinasien, Jahrringbreite, Hochlagenstandorte, Weiserjahr, *Juniperus*, atmosphärische Zirkulation.

SUMMARY

Juniperus polycarpos is a widely distributed tree species growing at the upper timberline in the mountain regions of northern Iran. According to correlation analyses between ring width index chronologies with local meteorological data, ring width is positively influenced by high spring and early summer rainfall and by warmer temperature in December prior to the growth season. Pointer years of extremely low and high values of tree growth during the 20th century were extracted by applying the so called Cropper technique. The spatial distribution and climatologic background of these pointer years was examined within a regional chronology network of 15 high elevation tree-ring sites enclosing Turkey, Iran, southern Russia, Kirghizia, Pakistan, Nepal and the Tibetan Plateau. The results show that the similarity of growth reactions at the north Iranian sites is greater with Asian high mountain regions than with the eastern Mediterranean area. Negative pointer years with a wide distribution within the study area are more common (1913, 1917, 1951, 1961, 1975, 1991) than positive pointer years (1940, 1981). The climatic analysis of pointer years and their relationship to certain modes of the atmospheric circulation can provide a basis for the interpretation of similar distribution patterns of pointer years further back in the past.

Keywords: Northern Iran, Asia Minor, tree-ring width, high elevation sites, pointer year, *Juniperus,* atmospheric circulation

1. INTRODUCTION

High mountain ecosystems are described to be particularly sensitive to climatic change (BENISTON and INNES 1998; MESSERLI and IVES 1997). Recently, considerable progress was achieved regarding the reconstruction of climate history by means of tree-ring analyses in different mountain areas of western and central Asia, namely (from east to west) on the Tibetan Plateau (e.g. WU and SHAO 1995; BRÄUNING 1999; 2001; BRÄUNING and MANTWILL 2004), the Himalaya (BORGAONKAR *et al.* 1999; YADAV *et al.* 1999; PANT *et al.* 2000; COOK *et al.* 2003), the Karakoram (ESPER 2000; ESPER *et al.* 2002; TREYDTE *et al.* 2006) and the Tian Shan (SOLOMINA 1999; ESPER *et al.* 2003). In mountain regions of the Middle East, tree-ring chronologies were developed in Turkey (KUNIHOLM *et al.* 1996; AKKEMIK 2003; AKKEMIK *et al.* 2005; AKKEMIK and ARAS 2005; TOUCHAN *et al.* 2003, 2005) and Jordan (TOUCHAN and HUGHES 1999; TOCHAN *et al.* 1999).

However, the mountain areas mentioned above are situated in different climatic regimes. Especially, the sum, seasonal distribution and origin of rainfall are varying considerably within and between the mountain systems (Fig. 1). For example, a Mediterranean winter precipitation regime is recorded in southern Turkey (Antalya). Towards the east, the influence of this regime is decreasing from northern Iran (Zanjan) to Pakistan (Peshawar), western Nepal (Jumla) and Tibet (Lhasa). During winter, the westerlies are divided into a northern and a southern branch over the Tibetan plateau. In contrast, decreasing monsoonal summer rainfall is recorded from east to west from Lhasa (predominantly summer rainfall) to Jumla (with a smaller, secondary rainfall peak during winter) and Peshawar (with equal summer and winter rainfall peaks). Further to the north, the stations in Naryn and Bijsk record rainfall during all seasons with a maximum in summer. This is typical for the temperate, more continental climate zone. The pattern recorded at Sotchi is affected by the stations' location between the eastern shore of the Black Sea and the foothills of the Caucasus. The area receives abundant rainfall throughout the year with a slight winter maximum.

The Elburz Mountains and the Koppeh Dagh tare situated in the Eastern part of the Mediterranean winter precipitation zone and near the border of the influence of the monsoonal regime (Fig. 1). Thus, climate in the north of Iran shows teleconnections to the North Sea (KUTIEL and BENAROCH 2002), to the south Asian summer monsoon (REDDAWAY and BIGG 1996) as well as to the El Niño - Southern Oscillation (ENSO) (NAZEMOSADAT and CORDERY 2000), although the physical mechanisms of the influence of the latter on subsequent autumn rainfall in northern Iran are not yet fully understood. Therefore, it is relevant to study the spatial distribution of extreme climatic events by comparing tree-ring chronologies from Iran with others from the Mediterranean region, the western and central Himalayas and southern Tibet. BRIFFA *et al.* (2002) presented an analysis of a northern hemispheric tree-ring network including a series of maps of annual climate variability since AD 1600. In this comprehensive dataset the mountain areas of Asia and especially the region of Asia Minor are still poorly represented. Thus, an analysis of climatically sensitive tree-ring sites from northern Iran would – even if preliminary – be highly useful and perhaps be complementary to the evidence from higher latitudes.

In the high mountain areas of Iran, *Juniperus polycarpos* is a widely distributed tree species growing at the upper timberline. The species forms the typical vegetation on the southern slope of the Elburz Mountains that belong to the Irano-Touranian floristic region of Iran (MOBAYEN and TREGUBOV 1970; KAZIMIERZ 1982). Presently, the state of dendroecological investigations in Iran is still fragmentary. First 300-year long *Juniperus polycarpos* chronologies were developed by LIPHSCHITZ *et al.* (1979) from three sites in north-western Iran and the Elburz Mountains. Unfortunately, these data are not available any more. Therefore, the tree-ring material for the current analysis of climate variability had to be recollected. In this study, we report on initial efforts to establish a climate-sensitive chronology network in northern Iran.

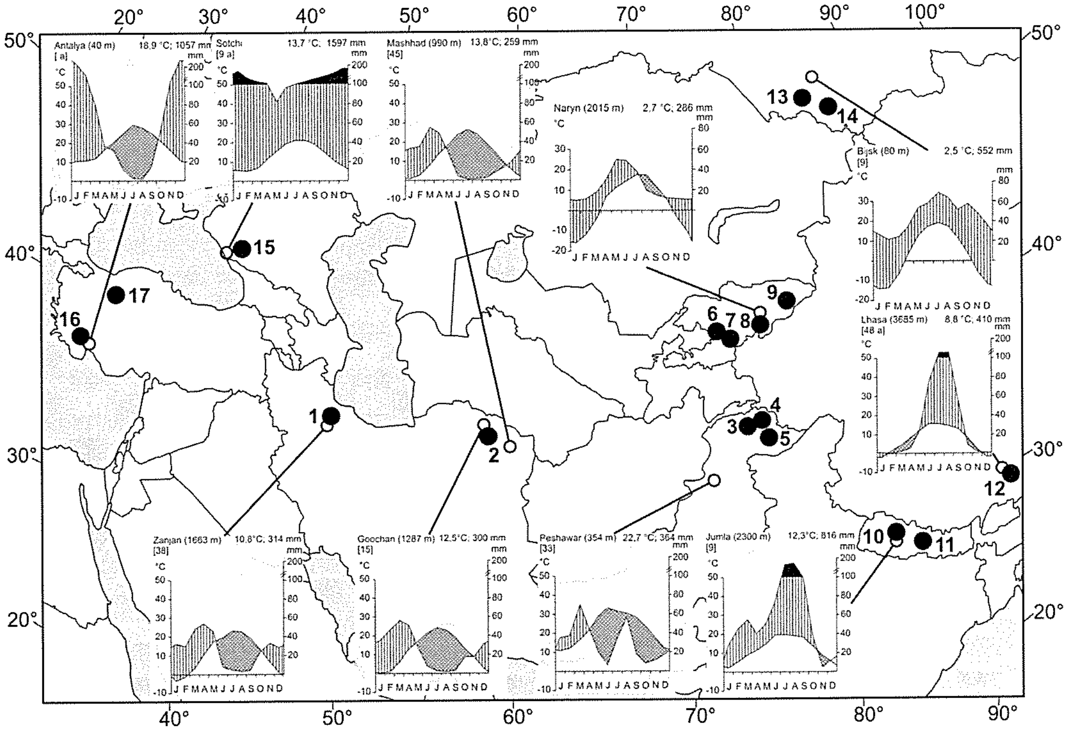

Fig. 1: Climate diagrams of relevant meteorological stations within the study region and locations of chronologies (numbers refer to listings outlined in Tab. 1 and 2)

Due to the limited lengths of the Iranian chronologies that could be obtained so far, we do not discuss decadal or even centennial variations in the tree-ring series, but focus on the climatic response of single extreme years. In indexed tree-ring curves, pointer years are defined as growth variations exceeding a determined threshold. As an advantage in comparison to correlation analyses using longer time series, studies of single pointer years might provide information about the forcing of growth anomalies by single extreme climate events like e. g. late frosts (SCHWEINGRUBER *et al.* 1991). Consequently, a detailed ecological interpretation of extreme growth deviations can be limited, if only time series of monthly means of climatic data are used for calibration (KIENAST *et al.* 1987). Pointer year analyses have been successfully accomplished in regional networks in Western Europe (KELLY *et al.* 2002), California (GARFIN 1998) and in the eastern Mediterranean region (HUGHES *et al.* 2001). Similar studies in High Asia were carried out on the Tibetan Plateau (BRÄUNING 1994), in the Karakoram (ESPER *et al.* 2001) and in the Tian Shan (ESPER *et al.* 2002). In the present study, we undertake a first effort to analyze the climatic response of pointer years of two *Juniperus polycarpos* sites from the Elburz Mountains during the 20th century. We then compare this regional evidence with pointer year records from the Mediterranean region in the west to the Tibetan Plateau in the east to initiate a new interregional database of climatically forced extreme growth years.

2. MATERIAL AND METHODS

2.1 The tree-ring material and climate data

Ring width chronologies of *Juniperus polycarpos* were developed at two upper tree-line sites in the Elburz Mountains and the Koppeh Dagh in northern Iran (Fig. 1, Tab. 1). The two forests of Zanjan and Lain exclusively consist of juniper trees and have an open character with a tree coverage of 20 % and 30 %, respectively. The trees do not exceed 8 m in height and 60 cm in diameter. Both tree stands grow on north facing slopes with an inclination of 20°-30° on deep sandy and clayey soils. Due to the long history of human impact on Iranian forests, old trees are quite rare. Most of the trees sampled for this study were younger than 100 years, so that the present analysis focuses on the 20th century. In addition, available chronologies from 15 sites from high mountain areas in western and central Asia are considered, which have in part been provided by other dendrochronologists. The locations, site names and tree species used are outlined in Tab. 1.

Tab. 1: Locations and sources of tree-ring data

No. in Fig. 1	Country	Site Name	Tree species	Chronology Code	Lat.	Long.	Elev.	Source*
1	Iran	Zanjan	*Juniperus polycarpos*	IZanj	36° 49'	49° 30'	2500	1
2	Iran	Lain	*J. polycarpos*	ILain	37° 00'	59° 21'	2100	1
3	Pakistan	Chaprot	*J. excelsa*	PChap1	36° 20'	74° 02'	2700	2
4	Pakistan	Chaprot	*J.s turkestanica*	PChap3	36° 20'	74° 02'	3900	2
5	Pakistan	Satpara	*J.s excelsa*	PSat1	35° 10'	75° 30'	3300	2
6	Kirghizia	Karagui	*J. turkestanica, J. semiglobosa, J. seravchanica*	KArt	40° 10'	72° 35'	2600	2
7	Kirghizia	Karagui	*J. turkestanica*	KHoch	40° 10'	72° 35'	3200	2
8	Kirghizia	Karabatkak	*J. sp.*	KKara	42° 11'	78° 11'	2850	2
9	Kirghizia	Sarekungey	*J. sp.*	KSare1	41° 40'	76° 26'	2800	2
10	Nepal	Samling Gompa	*Pinus wallichiana*	NSg	29° 26'	82° 54'	3850	3
11	Nepal	Ghorepani Pass	*Abies sp.*	NGhor	28° 25'	83° 45'	3220	4
12	China	Tibet	*J. tibetica*	CTDt	29° 18'	91° 58'	4450	3
13	Russia	Altai	*Larix sp.*	RJabwl	50° 52'	85° 14'	1400	4
14	Russia	Altai	*Larix sp.*	RUglal	50° 29'	87° 39'	2150	4
15	Russia	Caucasus	*Pinus hamata*	RKauka	44° 00'	40° 02'	1800	4
16	Turkey	Antalya	*J. sp.*	TAnta	36° 30'	30° 00'	1800	5
17	Turkey	Eskisehir	*Pinus nigra*	TEski	40° 00'	31° 05'	1400	5

* 1 = K. Pourtahmasi ; 2 = J. Esper; 3 = A. Bräuning; 4 = F. H. Schweingruber; 5 = P. I. Kuniholm

For the climatic interpretation of the chronologies, meteorological data from the nearest stations Goochan (37°10'N/ 58°30'E; 1287 m a.s.l.; 1984-1998), Mashhad (36°16'N/ 59°38'E; 990 m.a.s.l.; 1951-1995) and Zanjan (36°41'N/ 48°29'E; 1663 m.a.s.l.; 1962-1998) were used. The climatic regime at all stations is characterized by arid conditions during the summer season from May to October (Fig. 1). Annual rainfall is decreasing from west to east and amounts 314 mm, 300 mm and 259 mm at Zanjan, Goochan and Mashhad, respectively. Between 71 % (Zanjan) and 77 % (Mashhad) of the annual precipitation fall between November and April. However, the altitude between the tree-ring sites and the climate stations differs between 800 m and 1100 m which might cause difficulties concerning the assignability of the recorded rainfall amounts.

2.2 Development of tree-ring chronologies

The surface of all wood samples was smoothed with razor blades and ring widths were measured with a precision of 0.01 mm. Synchronization between the measured ring width series was accomplished by the software COFECHA and by visual comparison of extremely wide and narrow rings. To remove the biological age trend in the ring width data, a double de-trending procedure was applied to all series by using the program ARSTAN (COOK and HOLMES 1986). In this procedure, the raw ring width values were first standardized by calculating ratios from fitted straight lines or negative exponential functions. The resulting index values were then de-trended by calculating ratios from fitted cubic splines with a weighting factor equal to 128 years. This second de-trending procedure preserved about 75 % of the variance on time scales up to 100 years. Standard and residual chronologies were calculated as biweight robust means of all ring width series per site. The latter are residuals from autoregressive modeling of the standardized index series (COOK 1985).

The variance in earlier periods of tree-ring chronologies is frequently inflated due to decreasing sample size. This is particularly the case when the correlations of the series that are averaged to form a mean chronology are low (OSBORN *et al.* 1997). This holds true for the Iranian juniper chronologies. The other sites are less affected by this problem, since much older trees represent them. Thus, for all non-Iranian chronologies, the past 100 years are sufficiently replicated and a stabilization of variance was not necessary. For the Iranian chronologies, we adjusted the variance by multiplying the original chronology with the square root of the 'effective independent sample size' (OSBORN *et al.* 1997):

$$Y(t) = X(t)[n(t)/1+(n(t)-1)\bar{r}]^{1/2} \qquad (1)$$

, where X(t) is the original time series, n(t) the sample size and $\bar{r}$ the mean interseries correlation (BRIFFA & JONES 1990).

2.3 Analyses of climate-tree growth relationships

To detect the influence of climate on growth of Elburz junipers, two approaches were applied. First, linear correlation coefficients between monthly means of temperature and precipitation and ring width chronologies were calculated. To consider the influence of climate in the later part of the vegetation period on wood production during the next growing season by the formation of stored carbohydrates, correlation coefficients were computed for a 15-month period including July of the year prior to growth until September of the growth year. In addition, seasonal sums of rainfall were computed and correlated with the tree-ring index chronologies.

Second, the influence of climate on extreme growth fluctuations, the so called 'pointer years', was analyzed in detail. Among different ways for extracting pointer years from the index chronologies, the so called 'Cropper method' was chosen, which calculates the normalized differences between the growth value in year *i* and the mean growth value within a five-year moving window (CROPPER 1979):

$$Z_i = X_i - mean\ [\text{window}] / \ stdev\ [\text{window}] \quad (2)$$

Z_i = pointer year value in the year *i*

X_i = tree-ring index value in the year *i*

mean [*window*] = arithmetic mean of ring width within the moving window

$x_{i-2}, x_{i-1}, x_i, x_{i+1}, x_{i+2}$

stdev [*window*] = standard deviation of ring width within the moving window

$x_{i-2}, x_{i-1}, x_i, x_{i+1}, x_{i+2}$

Years with a value of Z_i being higher or lower than 0.75 or -0.75 were defined as positive or negative pointer years, respectively. Pointer years that are synchronous between both Elburz Mountain chronologies were selected and compared with the pointer years from the high mountain network over the common period of the 20^{th} century.

The climatic interpretation of the pointer years of the Iranian tree-ring sites was accomplished by calculating deviations of monthly series of temperature and precipitation data from the long-term means for the climate stations Zanjan and Mashhad. For pointer years, extreme weather conditions during the same 15-month period as for the correlation functions were regarded. Thus, relatively dry or humid periods or extraordinary warm or cold conditions during the winter months could be detected and assigned to corresponding deviations in tree growth rates (SCHWEINGRUBER *et al.* 1991; BRÄUNING 1994).

3. RESULTS

General properties of the resulting de-trended standard chronologies used for further analyses are given in Tab. 2. The low first-order autocorrelations and the high signal-to-noise ratios indicate that the influence of climate on the interannual growth variability of juniper is high (WIGLEY *et al.* 1984). These findings confirm that the juniper chronologies from Elburz are suitable for dendroclimatic studies. The two ring width chronologies are shown in Fig. 2 together with selected rainfall data from the neighboring climate stations. Pointer years are indicated by circles.

Tab. 2: Characteristics of Standard chronologies

No.	Chronology Code	Beginning date	End date	Record Length (Years)	No. of Trees	No. of Radii	AC (1) [1)]	SNR[2)]
1	IZanj	1896	2000	105	11	24	0.37	6.735
2	ILain	1842	2000	159	8	16	0.30	6.039
3	PChap1	1587	1993	407	14	23	0.31	3.455
4	PChap3	1141	1993	853	11	18	0.39	2.368
5	Psat1	1412	1993	582	13	14	0.44	2.91
6	KArt	1839	1995	157	29	51	0.47	7.846
7	KHoch	1316	1995	680	30	50	0.40	8.419
8	KKara	1650	1995	346	11	19	0.49	4.248
9	KSare1	1850	1995	146	4	8	0.75	8.28
10	NSg	1675	1998	324	10	13	0.62	5.57
11	NGhor	1740	1978	239	14	21	0.57	8.597
12	CTDt	1233	1998	766	13	13	0.44	3.408
13	RJabwl	1761	1994	234	15	30	0.70	20.819
14	RUglal	1581	1994	414	12	24	0.52	8.194
15	RKauka	1670	1991	322	7	7	0.60	2.385
16	TAnta	1360	1988	629	11	18	0.39	3.031
17	TEski	1306	1980	674	10	n. a.[3)]	n. a.	n. a.

[1)] AC (1) = first-order autocorrelation
[2)] SNR = signal-to-noise ratio
[3)] n. a. = not available

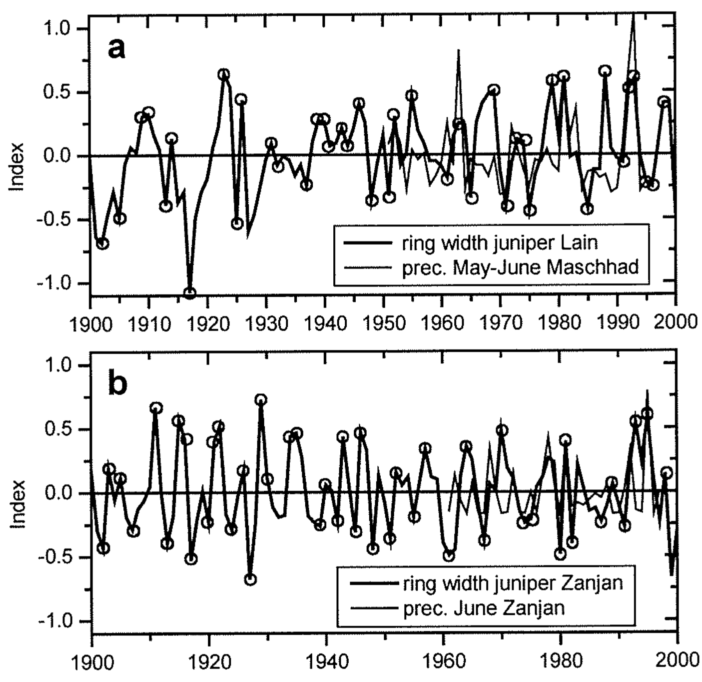

Fig. 2: Index chronologies from Lain (a) and Zanjan (b) with correlating (see Tab. 3) precipitation series from neighboring climate stations. Pointer years are indicated by circles

3.1 Correlation analyses

Correlation analyses of juniper ring widths with the climate data indicate positive correlations of tree growth with rainfall during the winter prior to the growing season and early summer (May, June) of the growth year at both sites (Fig. 3). The highest correlation coefficients found with the precipitation of a single month and seasonal means of rainfall are separately reported in Tab. 3. Summer temperature is generally negatively correlated with tree growth, although not always significantly. However, in case of Lain a significant positive influence of December temperature prior to the growing season is found with the climate data of Mashhad ($r = 0.54$; $p < 0.001$) and Ghoochan ($r = 0.60$, $p < 0.05$). Although this finding is consistent with results from other high-elevation juniper sites from central Asia (BRÄUNING 2001), it is presently difficult to interpret since detailed studies about tree physiology are still missing from this region. In general, tree growth of high elevation juniper sites in northern Iran is controlled by the favorable influence of late winter to early summer rainfall and the unfavorable influence of cold winters and hot and dry spring seasons. Although these relationships are found at both study sites, statistically significant correlation coefficients only occur at the eastern site (Lain).

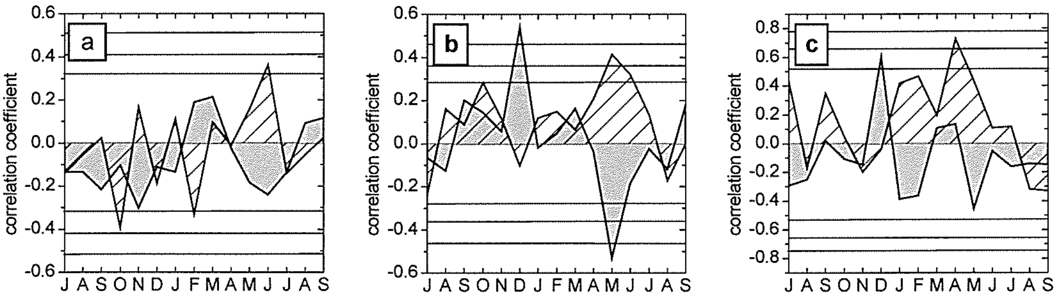

Fig. 3: Correlation functions from Zanjan (a) and Lain (b, c) juniper chronologies with temperature (grey) and precipitation (hatched) data from Zanjan (a), Mashhad (b) and Goochan (c) climate stations. Correlation coefficients were calculated for the period from July of the year prior to growth until September of the growth year. Horizontal lines indicate 0.1, 0.05 and 0.01 confidence levels

3.2 Pointer year analyses of Iranian junipers

The pointer years indicated in Fig. 2 were compared with the available climate data spanning the period 1951-1995. Four characteristic patterns of temperature and precipitation anomalies were found that repeatedly occur during negative and positive pointer years, respectively. We show these typical climatic anomaly patterns in Fig. 4 for the example of the Lain chronology and climate data from Mashhad. Positive pointer years always coincide with humid conditions during spring and early summer (Fig. 4a, b).

Nevertheless, two different patterns can be distinguished. During some years, the whole period from winter prior to growth to early summer of the growth year shows more humid conditions (Fig. 4a). In other years, the moister season is limited to spring, but then mild winter temperatures have a positive influence on growth in the following growth season (Fig. 4b). A majority of negative pointer years can be explained by dry conditions during a period from winter to early summer (Fig. 4c). Obviously, a lack of available soil water that could result from reduced winter snowfall or spring rains is responsible for growth reductions in juniper. A single pointer year (1985; Fig. 4d), however, was probably caused by extremely severe December temperatures during the preceding winter. The relationships between pointer years at Zanjan and local climate data are the same as discussed for Lain, but not shown here due to space limitations. As it could already be seen from the higher correlation coefficients with climate data obtained for the Lain chronology, the explanatory power for extreme growth years is also higher for Lain than for Zanjan.

Tab. 3: Correlation coefficients and explained variance (in parenthesis) between Iranian juniper chronologies and seasonal averages of precipitation data

Chronology Code/ Climate station (data period)	IZanj/ Zanjan (1962-1998)	ILain/ Mashhad (1952-1995)	ILain/ Goochan (1984-1998)
Jan-Jun	0.15 (2.2 %)	0.40** (16 %)	0.71** (50.4%)
Apr-May	0.11 (1.2%)	0.40** (16 %)	0.69** (47.6 %)
May-June	0.24 (5.8 %)	0.44** (17.6 %)	0.35 (12.3 %)
Highest correlation between ring width and rainfall data of a single month	0.36 (June)* (13.0 %)	0.41 (May)** (16.8%)	0.73 (April)** (53.3 %)

*p<0.05 **p<0.01

3.3 Spatial distribution of regional pointer years

To evaluate the similarity of growth reactions in northern Iran and the adjacent mountain regions, we first selected some of the most pronounced pointer years in the Iranian Mountains. Then we document the spatial distribution of pointer years over the whole tree-ring network for those years and describe some repeating large-scale geographic patterns that can be recognized (Fig. 5). Finally, we discuss possible inferences about the climatic circulation patterns that might trigger the reactions in tree growth.

The first spatial pattern of tree-growth reactions is found in the years 1975, 1991, 1913 and 1951. In 1975, the Iranian sites are the only ones recording negative pointer years as a consequence of drought (Fig. 4, Fig. 5a) with the exception of central Tibet. The Mediterranean, Caucasus, and two northern Pakistan sites show positive pointer years. At the same time, the tree-ring sites along an arc from southern Siberia, Kirghizia to Nepal show no distinct growth behavior. Similar meridional patterns are recorded in 1991 (Fig. 5b, no data from the western part of the study region) and 1913 (Fig. 5c), when some sites in Kirghizia and northern Pakistan show positive pointer years. In 1951 (Fig. 5d), positive pointer years in subalpine chronologies in the central Himalaya point to a weak summer monsoon.

Another growth pattern, integrating a meridional and a zonal component, is represented by the years 1961 and 1917. In 1961 (Fig. 5e), growth reductions in northern Iran are triggered by spring droughts (Fig. 4). Similarly, over a vast area from the Mediterranean coast to Pakistan and southern Siberia, growth reductions are recorded. However, the monsoon sensitive regions in the Himalaya and Tibet and northern Turkey and the Caucasus are not affected. Note that 1917 (Fig. 5f) is the strongest negative pointer year over the past several centuries in western Central Asia, with many trees in the Karakoram and Tian Shan performing a missing ring (ESPER *et al.* 2002).

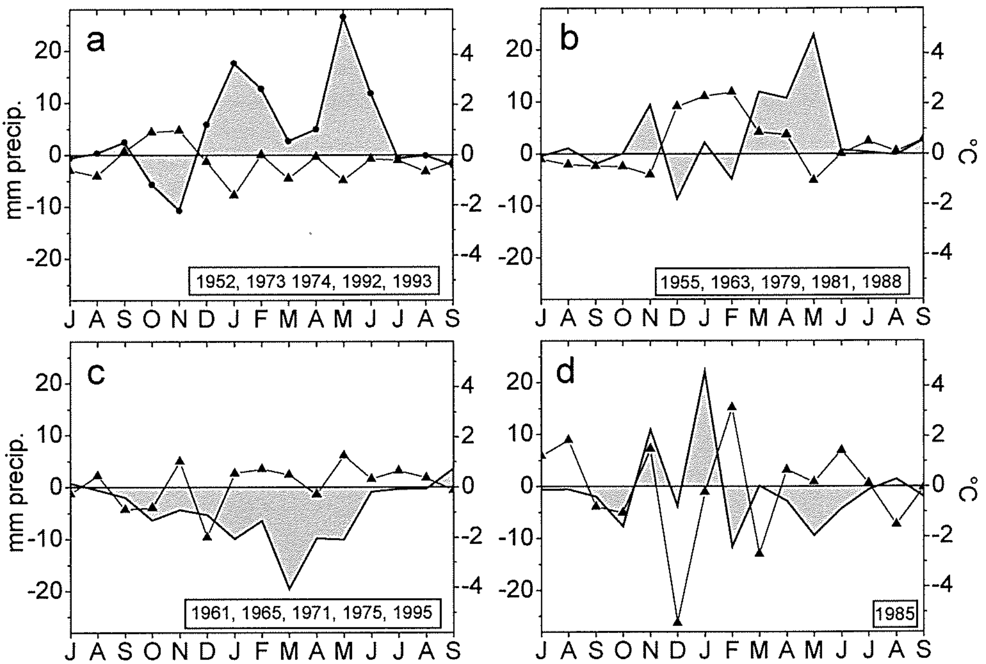

Fig. 4: Average climatic conditions at the station Mashhad during pointer years of the Lain juniper chronology. Triangles: temperature; grey shaded area: precipitation. The years that were considered to calculate the curves in Figs. a to d are indicated in text boxes. a and b: positive pointer years, c and d: negative pointer years

In comparison, common positive pointer years are less frequent. In 1981 and 1940, synchronous growth increases occurred in the Iranian Mountains (Fig. 5g, h). Their preconditions seem to be humid spring or early summer conditions together with average or above average temperatures during winter (Fig. 4). Again, no observational Iranian data are available to verify whether these conditions also hold true for 1940. Whereas in 1981, a belt of positive pointer years stretches from the Elburz Mountains to the Karakoram, this area is shifted further west from the eastern Mediterranean coast to Iran in 1940. It seems likely that the strength of the moisture-bringing westerlies influences the distribution of positive growth reactions between the eastern Mediterranean coast and Pakistan.

4. DISCUSSION AND CONCLUSION

Although some of the pointer years detected in the Lain chronology, like 1969 and 1991, can not be explained with the available climate data, a vast part of pointer years corresponds to the few climatic patterns outlined in Fig. 4. Although we can not exclude that some of the older pointer years shown in Fig. 2 were caused by different climatic causes, it is reasonable to suppose that the major part of these events were triggered by the same climatic anomalies that explain the occurrence of the pointer years after 1951, when climate data are available. However, reverse conclusions regarding the occurrence of pointer years and climate conditions can not be drawn. For example, even though the winters 1973 and 1974 were as cold as the one in 1971, no negative growth reactions were recorded in those years. Whether these so far unexplained ring width variances are related to the limited representativeness of the climate data for the tree sites or local human impact can not be decided yet and needs further research. On the other hand, cold winter temperatures and dry spring conditions do not necessarily occur separately, like e.g. in 1965. It also seems important that short-lasting dry periods of perhaps up to 8 weeks that could influence tree growth might not appear in the monthly rainfall records. The correspondence of the climatic patterns triggering pointer years that are outlined in Fig. 4 shall be assigned to certain modes of atmospheric circulation in future work.

HUGHES *et al.* (2001) investigated a tree-ring network comprising 23 chronologies of different tree genera in the eastern Mediterranean region. Response function analyses using regional means of climate data revealed a high sensitivity of most sites to precipitation during spring and early summer, especially during May and June. The correlation analyses presented here for juniper chronologies from north Iranian Mountains show very similar relationships to local climate with highest sensitivities to rainfall during early summer (Fig. 2). However, the influence of winter temperature on tree growth is higher in the Iranian Mountains than in the Mediterranean region. Very likely this is because of the higher elevations and the more continental climate at the Iranian sites (Fig. 1).

Several studies have demonstrated that the spatial patterns of pointer year distribution are caused by specific atmospheric circulation patterns. KELLY *et al.* (2002) assigned signature years in European oak chronologies with certain modes of the Arctic Oscillation. HUGHES *et al.* (2001) were able to correlate the occurrence of pointer years in the eastern Mediterranean region with differences in the circulation over the North Atlantic. If a strong high pressure cell forms above the northern Atlantic in winter, the tracks of winter cyclones are blocked and forced southward, leading to abundant rainfall in the eastern Mediterranean region. Trees benefit from the moisture surplus in the succeeding growing seasons and form wider rings. If, however, no high pressure system is developed in the North Atlantic sector, the transfer of moisture will be accomplished by a meridional circulation component. This leads to a precipitation deficit in the Mediterranean region and causes the formation of narrow tree rings.

Some of the negative pointer years listed by HUGHES *et al.* (2001) correspond with exceptionally narrow rings found in the Iranian juniper chronologies (Fig. 2), namely 1961, 1945, 1942 and 1935. However, HUGHES *et al.* (2001) define a signature year if more than 18 of 23 chronologies exhibit the same growth trend. Therefore, their results are not directly comparable with ours due to the different pointer year technique applied in this study, where we detected outlying growth values rather than growth tendencies. On the other hand it could be shown that years with large growth changes in a site chronology mostly correspond with years in which a majority of all trees at a site exhibit the same growth tendencies (BRÄUNING 1994). Hence, not all signature years in the eastern Mediterranean region coincide with pointer years in northern Iran. Whether these differences are caused just by the different ways of calculation of pointer years or if they indicate different circulation patterns needs further investigation. Possibly, the Elburz Mountains could be influenced by a circulation component evolving from the Caspian Sea that could be relevant in those years.

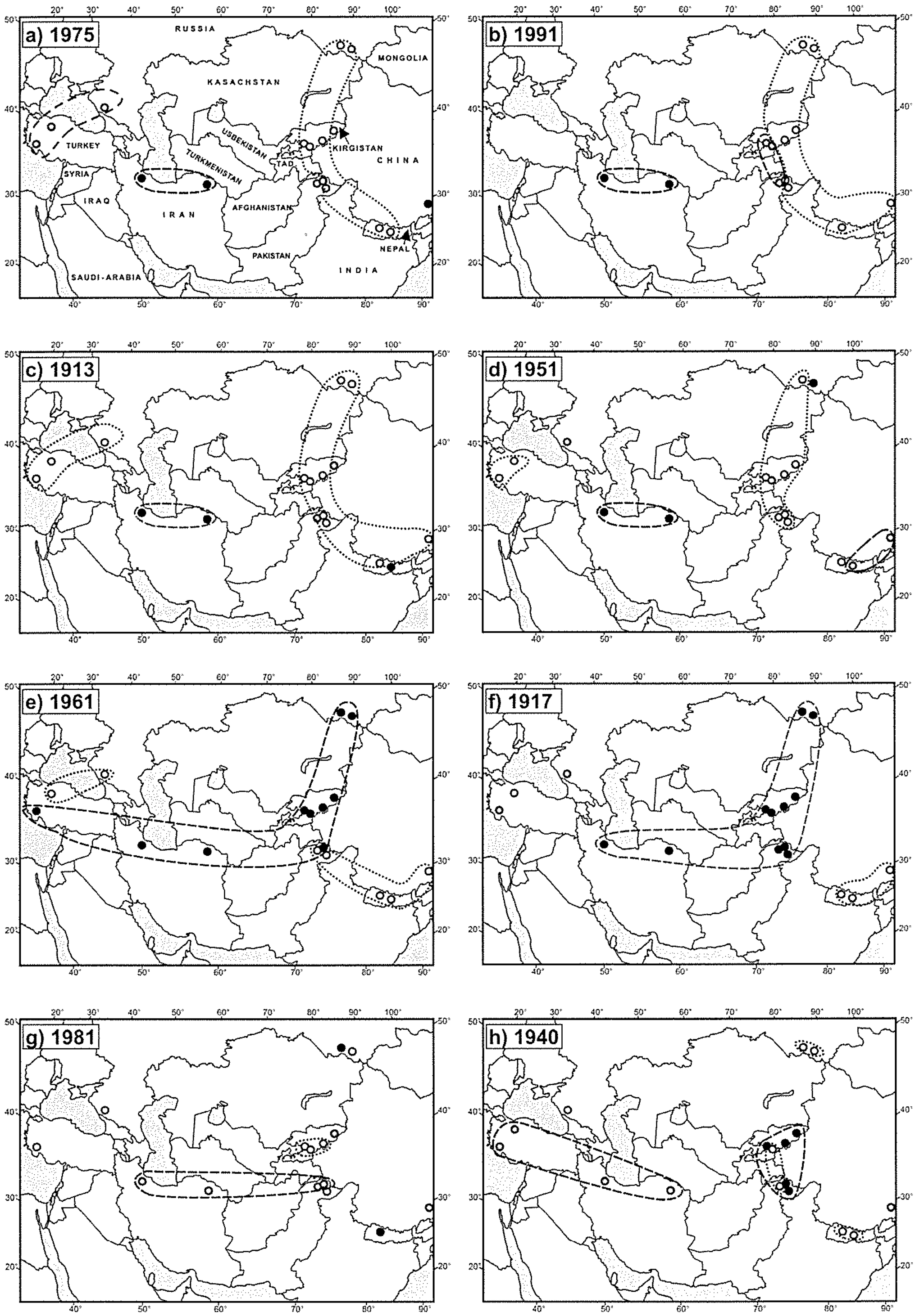

Fig. 5: Distribution patterns of negative (a-f; black circles) and positive (g-h; gray circles) pointer years from the Near East to the Far East. Normal years are shown in empty circles, regional identical growth reactions are encircled by dashed lines

Interestingly, there is almost no coincidence between the positive pointer years recorded in the eastern Mediterranean region and northern Iran. In 1975 and 1917, negative pointer years are recorded in the Iranian Mountains in contrast to the eastern Mediterranean region (Fig. 5a and f). In general, the Iranian chronologies show a greater similarity to chronologies from western High Asia from the eastern Mediterranean region. Despite of the shortness of the analyzed time period we can already conclude that common negative pointer years are more frequent than positive pointer years. Furthermore, local pointer years that are restricted to the Iranian Mountains can be distinguished from regional pointer years that affect a broad belt of sites simultaneously. Finally, the spatial patterns of negative and positive pointer years occur repeatedly and thus seem to mark certain varying intensities or circulation modes of the west wind drift.

Our initial study shows that chronologies from Iranian junipers can be assigned to distinct local climate anomalies and thus can be utilized in inter-regional tree-ring networks to evaluate the distribution and intensity regional circulation patterns. However, the density and length of Iranian tree-ring chronologies need to be improved considerably to enhance the potential for extrecting additional climatic information that can be gained from dendroclimatological networks (BRIFFA *et al.* 2002; KELLY *et al.* 2002). The wide distribution of *Juniperus polycarpos* (syn. *J. excelsa*) and other juniper species of the section *Sabina* from Afghanistan, Baluchistan, Iran, Caucasus, Turkey to the Arabian Peninsula and even to Ethiopia (V. WISSMANN 1972) provides a high potential for the development of a dendroclimatological network for the semiarid mountain belt of northeastern Africa, the Middle East and western High Asia. This could help to minimize the influence of species heterogeneity on the reaction of tree growth to climate and to create large-scale monospecific networks like it was successfully done for oak in Europe (KELLY *et al.* 2002) or for conifer species in the boreal zone (SCHWEINGRUBER *et al.* 1991).

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