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TREE-RING CHRONOLOGIES FROM UPPER INDUS BASIN OF KARAKORUM RANGE, PAKISTAN

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Abstract

Four coniferous species *i.e. Picea smithiana* (Wall.) Boiss, *Cedrus deodara* D. Don, *Pinus gerardiana* Wall. Ex Lamb. and *Juniperus excelsa* M. Bieb. were sampled from seven catchments in the Upper Indus Basin of Himalayan region of Pakistan. The purpose of this investigation was to explore dendrohydrological potential of these species. Core samples of these species show good inter-and intra-species cross-matching, despite being collected from different areas. The quality control program, COFECHA showed that wood samples of these species exhibit 0.68 to 0.92 correlation with master chronologies and 0.23 to 0.42 mean sensitivity. Standardized dated chronologies of these species are presented which span from 212 years to 486 years with a wide range of growth rates. Residual chronologies show higher mean sensitivity (0.205-0.411) while in general, higher serial correlation was recorded in arstan chronologies. Values of expressed population signals (EPS) were higher than 0.850, which are encouraging for future advanced tree-ring investigation. It is suggested that these chronologies have a high potential for dendrohydrological investigation. However, there is a need for larger sample sizes and further extension of these chronologies into the past.

Introduction

Pakistan is one of the world's most arid country, with an average rainfall of under 240 mm per year (World Bank, 2005). The population and the economy are heavily dependent on an annual influx of water primarily from melting snow into the Indus river system. A severe decline in the flow of the Indus River poses a great threat to Pakistan - especially ones of unprecedented severity and duration (so-called "mega droughts"). Elsewhere there is strong archaeological evidence for the destabilizing influence of past droughts on previous civilizations and also on advanced agricultural societies (e.g. USA) - something that should resonate today given the increasing vulnerability of modern water-based systems (both agricultural and hydro-electrical) to relatively short-term droughts. Understanding how past river-flow changes have developed and persisted is a timely scientific problem. In a recent study of the country's water resources by the World Bank the subheading was "Water economy: Running dry". This is despite IPCC predictions using general circulation models (GCMs) of initial increases in river flow due to the melting of glacial ice reservoirs. After this, water scarcity is forecast to become severe and widespread. However, the World Bank report clearly stated that the science is in its infancy and that there is an inadequate knowledge base. Our project aims to help address this point.

Individual years of reduced river-flow are not necessarily good indicators of cumulative environmental and socio-economic impacts. One dry year may be accommodated without undue environmental and economic harm providing it is sufficiently offset by wetter conditions the following year. What really matters is duration because recovery from the cumulative damage of consecutive low river-flow /drought years is more difficult. This is where a long record of past river-flow is critical. The sustainable management of the water resource depends on knowing the range of natural variability. Monitored river discharge records of the Indus River are simply too short (<40 years) to capture the range of past conditions – a widespread problem often faced throughout the world. The solution adopted in several other countries, including the USA, has been to use a surrogate or a proxy-climate indicator to provide the long record. The only suitable proxy that has been proven to be sensitive to changes in moisture supply, able to provide broad spatial coverage, has clearly-resolved annual resolution, can be exactly dated and provide long enough records are tree-rings. Dendrohydrology is a branch of dendrochronology which deals with hydrological problems, using annual growth rings of trees. In these studies stream flow, flood height, water table change, drought years, age of delta, sedimentary deposits or energy are able to be determined or reconstructed.

Fortunately, the northern area of Pakistan has forests containing a range of species that we now know can provide long annual tree-ring chronologies (Ahmed, 1987). In Pakistan, tree-rings have been used for . . .

1- Providing dated chronologies of *Abies pindrow* (Ahmed 1989) and *Picea smithiana* (Ahmed and Naqvi 2005, Khan *et al*, 2008), Ahmed and Sarangzai, 1991b).

Determine age and growth rates of forest trees (Ahmed 1988a, Ahmed and Sarangzai 1991a, Wahab *et al*., 2008, Ahmed *et al*., 2009a).

2- In population dynamics studies (Ahmed, 1988b, 1989, 1990a,b 1991).

3- Evaluate growth climates response of forest trees (Ahmed *et al* 2009b, 2010a, 2010b, 2011).

4- Climatic investigation (Esper 2000, Esper *et al* 1995, Treydte *et al*., 2006).

No dendrohydrological work has been carried out in Pakistan. This first paper is a part of a series in which we aim to develop a network of tree-ring chronologies from the catchments of the Upper Indus River and reconstruct river-flow for at least the last 200 years. The reconstructions will provide key information for the management of the river as well as provide a baseline from which to evaluate scenarios of future climatic change. The research will also provide important information to wider regional studies on the Asian Monsoon system thereby raising the international profile of Pakistan.

Material and methods

Within each catchment area location, sites were selected where growth was expected to be limited by environmental factors. In practice this meant that samples were usually on steep slopes or ridges. Coring techniques and sample preparation were carried out according to the method outlined by Stokes and Smiley (1968), Ahmed (1984) and Ahmed and Ogden, (1985).

Cross-dating

Cross dating is the basic requirement and the most important principle in tree-ring research (Fritts 1976). The skeleton plot method (Stokes and Smiley 1968) was followed during visual (under stereoscopic microscope) cross-matching of the cores of the same species and site. From each site at least 15 trees (two cores per tree) were sampled. Good cross-matching depends on …

1- Better site selection
2- Good circuit uniformity of stem
3- Distinct ring boundaries
4- Variability of ring-width (sensitivity)
5- Low number of false and missing rings
6- Sufficient sample size

During cross-matching each ring was assigned to its particular year of formation. False and missing rings are also detected during this process. Visual cross-dating itself determine the suitability of the cores, but visual cross-matching is a subjective method and it cannot be used in statistical analysis. Consequently it is necessary to convert these observations into numerical form. Therefore the ring-width pattern of every cross-matched core was measured in fractions of millimeters, using computer compatible Velmex measuring system, attached to video monitor, printer and stereoscopic microscope.

Statistical Analysis

According to Fritts (1976) certain statistics provide an objective quantitative base for evaluating the dendrochronological potential of a tree-ring chronology. These statistics were obtained by running programs COFECHA, ARSTAN in the Laboratory of Dendrochronology and Plant Ecology, Department of Botany, Federal Urdu University of Arts, Science and Technology, Gulshan-e-Iqbal Campus, Karachi.

Program COFECHA

Visual cross-matching of wood samples were verified, using a quality control program COFECHA by Holmes (1992) and described by Grissino-Mayer (2001) which performed 4 main jobs, step by step

1- Standardization of wood sample with a cubic smoothing spline or default value = 32 years spline.
2- Create master chronology by averaging together the ring-widths of similar year for each wood sample (index values for each year).
3- Summarizes the correlation of each segment against the master chronology by default and broke series into 50 year segments with 25 year overlap.
4- Then each wood sample (core) is correlated with the master chronology. This master chronology is provided only for dating purpose and not used for other analysis. As a result the program gives various statistics, however following are important at this stage

1- Correlation of a wood sample with all other wood samples
2- Mean sensitivity of different wood sample
3- Autocorrelation
4- Average values of various statistics

This is an important phase, because at this stage, some wood samples or the part of a wood sample may be reanalyzed or excluded from the study due to low correlation or unsuitability of the sample.

Program ARSTAN

This methodology, ARSTAN (Auto Regressive Standardization) was developed by Cook from University of Arizona in 1980 to deal with a certain class of problem that is common to tree growing in closed-canopy forest environments: the endogenous disturbance problem. A detailed description of this program is contained in Cook (1985) and Holmes (1994). This program also gives various statistics in which Expressed Population Signal (EPS) and signal to noice ratio (SNR) are used to determine quality of a chronology. Number of trees and cores that cross-dated.

Result and discussion

Sampling locations of Upper Indus catchments are shown in Fig.1, while ecological characteristics of sampling site and tree sample size is given in Table 1. Four coniferous species were collected from seven sites of Diamer and Gilgit district of Northern areas of Pakistan. Sample sites were located from 2300 m to 3250 m elevation with 26 to 45 degree of slope. Each site and tree species provided good cross-matching under the microscope. Each tree species show similar narrow rings not only among the same species but pointer years or rings of one species and site are also coincide with other species and site. Therefore, it is suggested that despite different species and sites with various distance, this area and species are under similar extreme climatic condition. However, for confirmation by statistical method, ring-width data of each species was subjected to quality control computer program COFECHA and the summarized results are presented in Table 2.

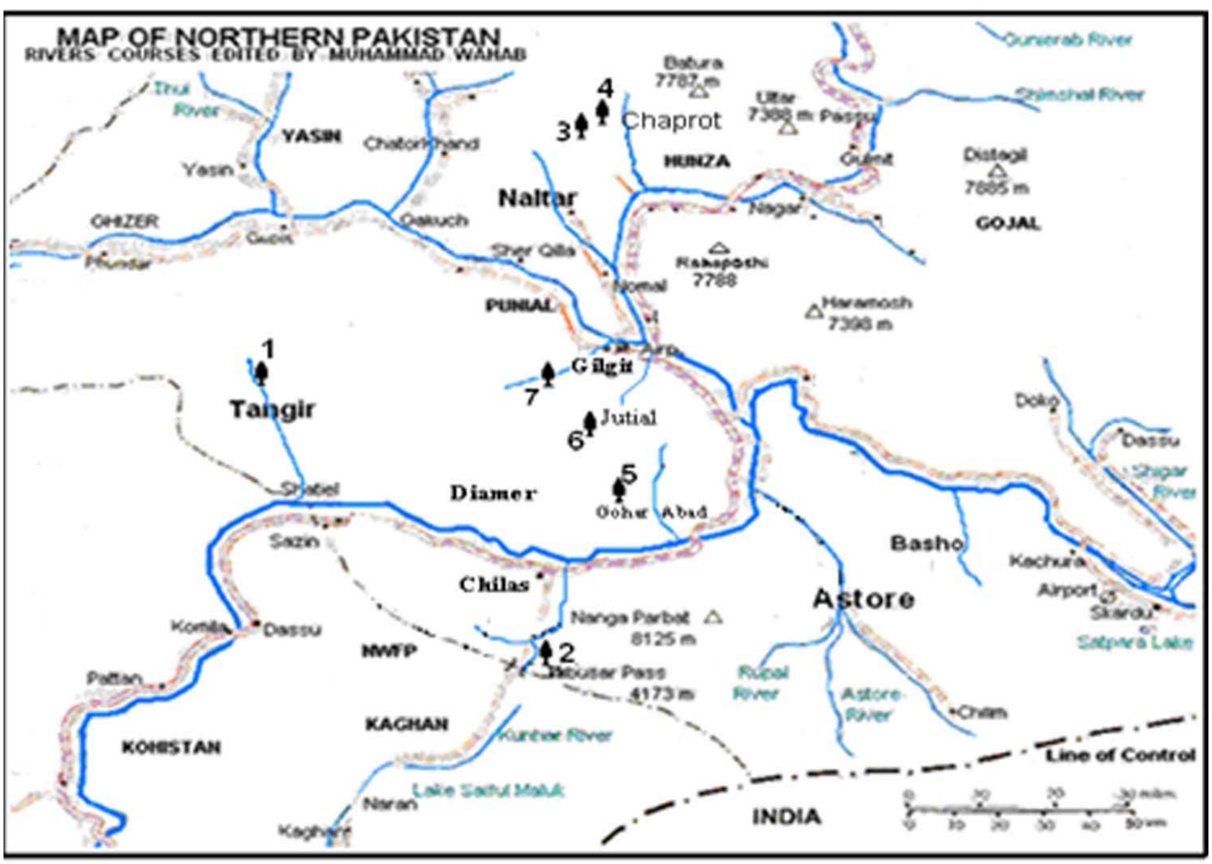


Fig.1. Sampling sites from catchments of Upper Indus Basin. Details of sites are given in Tabl.1.

Table. 1. Ecological characteristics of sampling sites and Sampling size.

Species		Site Name	Latitude North	Longitude East	Elevation in meters	Exposure	Slope degree	* Tree	* Cores
Cedrus deodara	1	Tangir (Diamer)	35 º 39	73 º 32	2320	NW	28	15	30
Juniperus excelsa	2	Babusar (Diamer)	35 º 37	74 º 04	3200	SE	32	16	32
	3	Chaprot Gilgit	36 º 14	74 º 16	3130	N	45	30	49
Pinus gerardiana	4	Chaprot (Gilgit)	36 º 14	74 º 16	2850	N	26	18	32
	5	Gohar Abad (Diamer)	35 º 32	74 º 30	2650	E	34	16	32
Picea smithiana	6	Jutial (Gilgit)	35 º 50	74 º 20	3250	N	40	20	40
	7	Kargah (Gilgit)	35 º 53	74 º 11	2989	NW	34	14	23

COFECHA statistics shows that wood sample of each species are highly correlated with the master chronology of its own species. It ranged from 0.682 (*Pinus gerardiana* of Chaprot) to 0.917 (*Picea smithiana*) from Jutial. Sixteen other chronologies from northern areas (Ahmed *et al* 2010a, b, c) are also available for comparison.

Our *Cedrus deodar's* correlation (0.767) with master chronologies with mean sensitivity (0.386) was considerably higher than Kalash, Gol National Park, Chitral and Dir while lower than *Cedrus deodara* (0.90 to 0.534) from Mushfar respectively. *Pinus gerardiana* samples collected from Joti and Mushkin show higher correlation (0.83-0.85) and mean sensitivity (0.38-0.41) than present sample. However, present samples show better values (0.68 - 0.74) (0.30 - 0.35) than Gol National Park (Ahmed *et al* 2010c) and Kalash (Ahmed *et al* 2010b). Our *Picea smithiana* from Jutial and Kargah have higher correlation and mean sensitivity than Ahmed *et al* (2010b) samples collected from Chera and Nalter. Trees from Tangir and Kargah produced slightly wider rings, compared to other sites, however slowest growth (0.82) was recorded in *Juniperus excelsa* from Chaprot site. Amount of autocorrelation was higher but within the range of other studies in Pakistan and elsewhere. In addition, it was minimized, using filter technique. Overall these species may be considered as suitable and sensitive species for advanced dendrochronological investigations.

Table.2. Summary statistics of COFECHA and ARSTAN of different sites.

	COFECHA					ARSTAN		
Species and Sampling Sites	**[1]Corr With master**	**[2]Mean msmt**	**[3]Std Dev**	**[4]Auto corr**	**[5]Mean sens**	**[6]Rbar**	**[7]SNR**	**[8]EPS**
1. *Cedrus deodara* Tangir Diamer	0.767	1.07	0.541	0.627	0.386	0.550	14.489	0.935
2. *Juniperus excelsa* Babusar Diamer	0.743	0.88	0.525	0.617	0.423	0.619	6.94	0.909
3. *Juniperus excelsa* Chaprot Gilgit	0.846	0.82	0.416	0.736	0.326	0.840	3.50	0.944
4. *Pinus gerardiana* Chaprot Gilgit	0.682	0.97	0.432	0.681	0.297	0.599	17.497	0.962
5. *Pinus gerardiana* Gohar Abad Diamer	0.744	0.91	0.444	0.575	0.354	0.489	19.683	0.947
6. *Picea smithiana* Jutial Gilgit	0.917	0.90	0.462	0.668	0.364	0.847	22.81	0.992
7. *Picea smithiana* Kargah Gilgit	0.710	1.05	0.411	0.716	0.228	0.567	12.164	0.938

Note: 1= correlation with master chronology, 2= Mean ring width, 3= Standard deviation, 4= Autocorrelation, 5= Mean sensitivity, 6=Mean inter series correlation, 7=Signal-to-noise ratio and 8= Expressed population signal.

Ring width pattern of seven raw chronologies are shown in (Fig.2) only 100 years period is presented here. Arrows are pointed to the narrow rings in similar years in all chronologies. These so called "pointer years" are 1917, 1944, 1947, 1971 and 2001. These pointer years are also identified in other ring-width network of Pakistan, showing trees reliability, sensitivity and response of similar extreme climatic events over a wider area (Ahmed 1989, Ahmed and Naqvi 2005, Ahmed *et al* 2009b, 2010a, 2010b, 2010c, Khan *et al* 2008).

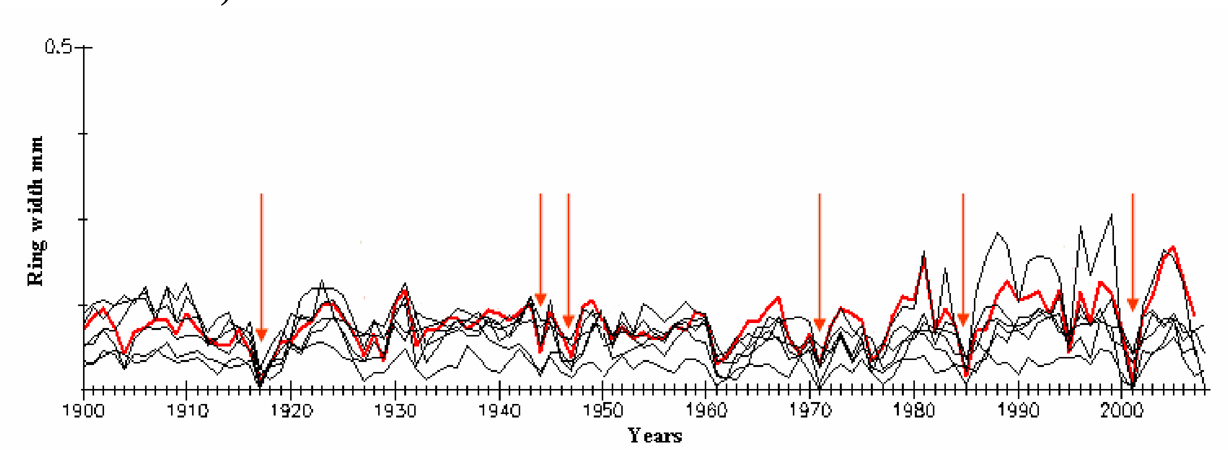


Fig. 2. Pointer years in raw ring width chronologies of four coniferous species from seven different catchments of Upper Indus Basin. Only pointer years of the last century are shown.

A summary statistics of various chronologies using autoregressive standardization program ARSTAN is presented in Table.3 while graphic representations of their samples size and residual chronologies are shown in Fig. 3.

Table.3. Summary Statistics of various chronologies of different coniferous Species from Upper Indus Basin (Gilgit and Diamer) by using Tree ring program ARSTAN (Autoregressive standardization).

S.No	Species and Sites	Time Interval (Years)	Chronology	Mean index	Standard deviation	Skewness coefficient	Kurtosis coefficient	Mean sensitivity	Serial correlation
1	*Cedrus deodara* Tangir	1661-2008.A.D (348)	Standard	0.980	0.375	0.217	3.435	0.336	0.482
			Residual	0.984	0.322	-0.371	3.314	0.402	-0.096
			Arstan	0.988	0.370	-0.013	3.378	0.391	0.495
2	*Juniperus excelsa* Babusar	1690-2007.A.D (318)	Standard	0.938	0.387	0.356	2.810	0.362	0.491
			Residual	0.968	0.330	0.050	3.145	0.411	-0.119
			Arstan	0.970	0.378	0.454	3.297	0.338	0.495
3	*Juniperus excelsa* Chaprot	1670-2008.A.D (339)	Standard	0.986	0.321	0.226	3.328	0.301	0.416
			Residual	1.000	0.291	0.312	3.460	0.336	0.020
			Arstan	0.748	0.365	0.738	3.076	0.310	0.731
4	*Pinus gerardiana* Chaprot	1797-2008.A.D (212)	Standard	0.986	0.271	-0.248	3.354	0.224	0.552
			Residual	0.996	0.219	-0.504	3.486	0.266	-0.055
			Arstan	0.998	0.240	-0.345	3.131	0.219	0.419
5	*Pinus gerardiana* Gohar Abad	1738-2007.A.D (270)	Standard	0.975	0.291	-0.228	2.916	0.295	0.395
			Residual	0.983	0.269	-0.333	2.753	0.348	-0.122
			Arstan	0.984	0.291	-0.247	2.960	0.292	0.396
6	*Picea smithiana* Jutial	1523-2008.A.D (486)	Standard	0.973	0.330	-0.091	3.127	0.344	0.338
			Residual	0.995	0.304	-0.328	3.314	0.387	-0.054
			Arstan	0.996	0.334	-0.060	3.122	0.325	0.381
7	*Picea smithiana* Kargah	1680-2008.A.D (329)	Standard	0.984	0.195	-0.328	3.663	0.178	0.346
			Residual	0.997	0.179	-0.584	4.741	0.205	-0.079
			Arstan	0.997	0.198	-0.252	3.497	0.174	0.365

According to Speer (2010) about 20 trees (two core / tree) per site or stand, can remove individual tree variability and yield a stand-level variability while Fritts (1976) suggested 12 trees (two cores/tree). A reliable sample depth may also be achieved by using expressed population signal (EPS). Except *Juniperus excelsa* all chronologies fulfill the minimum requirement of sample depth (12 trees/site) up to certain years. Due to extremely narrow rings in *Juniperus excelsa* samples, cross-dating was difficult, hence many cores were rejected. *Cedrus deodara* required more sample, for reliable statistical results and cross-dating beyond 1750AD, *Pinus gerardiana* Chaprot beyond 1850AD, *Pinus gerardiana* Goharabad beyond 1800AD and *Picea smithiana* needed more samples beyond 1570AD for reliable cross-dating (Fig. 3). However, a chronology of a few samples can still be well dated and useful.

Wood samples (without standardization) Fig.3 shows different growth at different period of their life. *Juniper excelsa* from Chaprot produced fast growth around 1800, 1850AD and slow growth around 1830AD with continuous slow trend up to year 2000 while *Pinus gerardiana* from same site show fast and slow growth in different periods. Therefore, it is suggested that not only different species in different sites but different species from the same site also show different growth in different period of life.

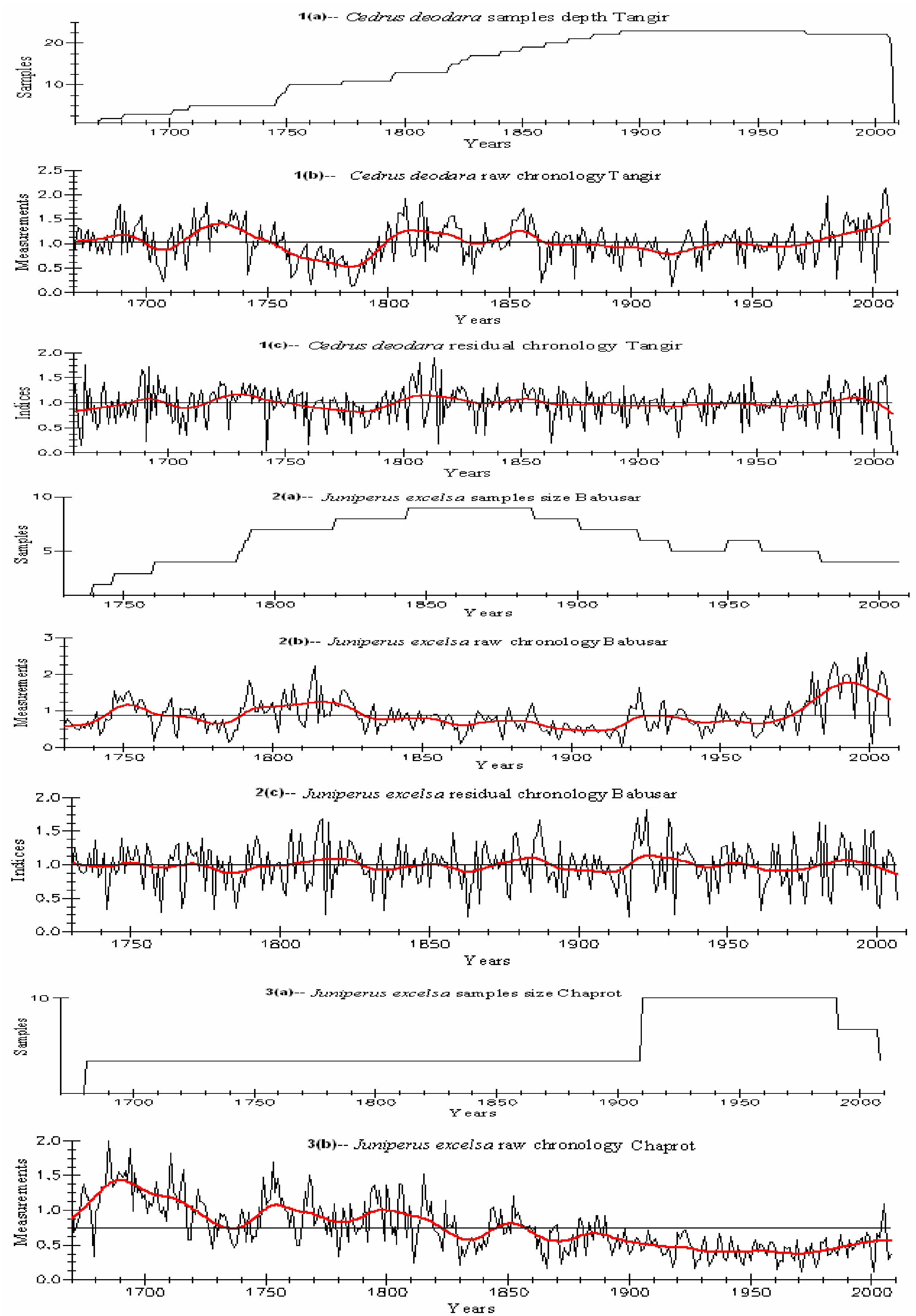
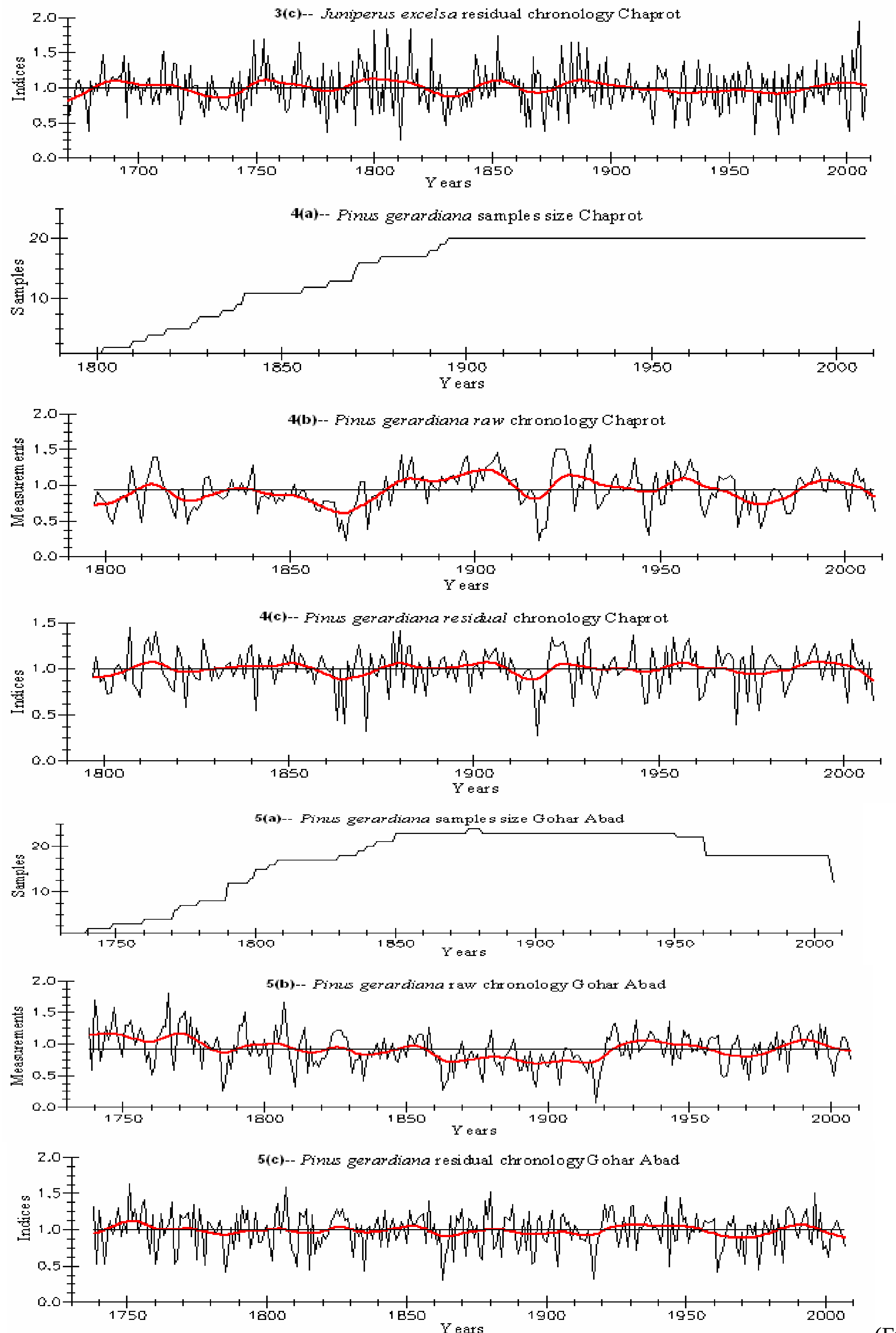


Fig. 3. Seven raw and standardized residual chronologies with sample depth from Upper Indus Basin are presented here.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4(a)-- Pinus gerardiana samples size Chaprot
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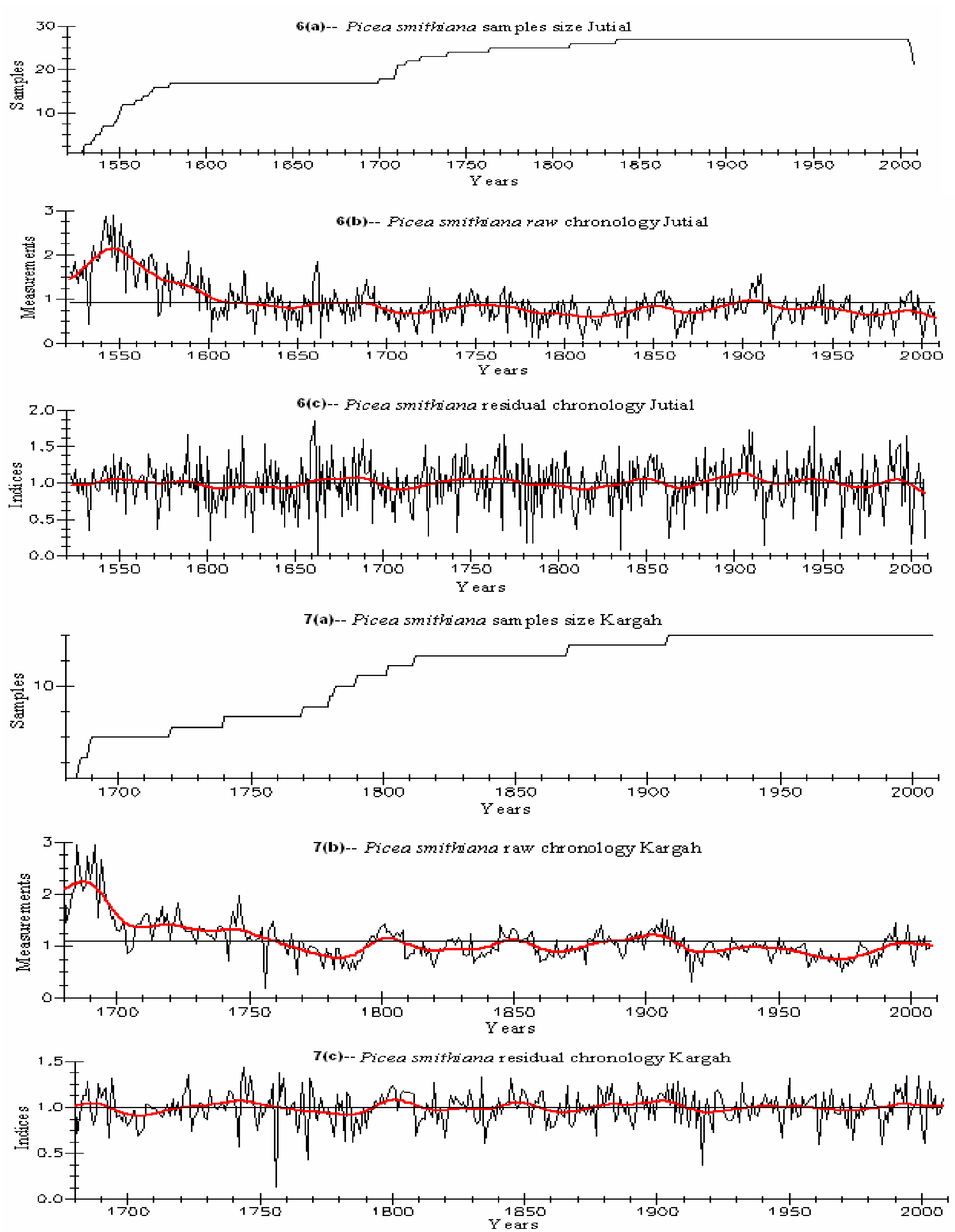

(Fig.3.Cont'd).

Following cross-dating, the computer program ARSTAN was employed to detrend each series and create master tree-ring chronologies. Three different type of standardized chronologies are produced for each site and some important statistics are given in Table 3. First standard chronology was obtained which was simply the detrended ring-width. Second, the residual chronology was created from univariate autoregressive modeling.

Third, the ARSTAN chronology was created by reincorporating the auto regression model into the residual chronology.

Standardization process remove age-related growth trend (high frequency signal) and maintain low frequency variability or signals, in tree-ring chronology which is useful to determine long term trends in past climate.

Dendrohydrological response depends on dendroclimatological response of the tree-rings, mean sensitivity, standard deviation and 1^{st}-order auto-correlation coefficient (serial correlation). These values are used to judge climatic values (Fritts and Shatz, 1975) of trees which are also useful to describe hydrological potential of tree-ring series. Table 3 revealed very little difference between standard and Arstan series, using these statistics. In addition with few exceptions, little difference is recorded in coefficients of skewness and kurtosis. According to Cook (1985) gain spectrum, cross-spectral and visual chronology comparison has not revealed any significant difference between standard and Arstan chronologies. However, he was of the opinion that Arstan chronology might underestimate persistent extremes compared to the standard chronology.

Standard chronologies (auto-correlation included) which is an average of the index values from the standardization and Arstan chronologies are not presented in Fig.3 in this paper. Since residual chronologies has all auto-correlation stripped from the series, marking it more suitable chronologies for regression analysis but not necessarily the most sensitive to the signal of interest (Speer, 2010), are presented here in Fig.3.

Residual chronologies (Table. 3) show higher values of mean sensitivity (0.205 to 0.411) which is the year to year variability of ring-width. According to Speer (2010) value around 0.2 is generally sensitive enough and accepted for climatic reconstruction. In addition values of mean sensitivities are higher in residual chronologies, indicating the high-frequency radial growth variation through the removal of lagged growth (Cullen 2001). Standard deviation values, another measure of radial growth variability, ranged from 0.179 to 0.322 in residual chronologies. The coefficient of skewness and kurtosis are included to assess any higher-order effects on the probability distribution owing to the method of standardization.

Average correlation among trees for the common overlap period among series is expressed by Rbar. It is used to examine the common signal strength of the chronology (Cook *et al*, 2000). Highest strength (0.84) was seen in *Picea smithiana*, Jutial and *Juniperus excelsa* from Chaprot. Other values were also with in the range of other studies elsewhere. Chronology confidence and strength of the common signal in the chronology is also estimated by EPS. Though a value of 0.85 is considered reasonable by Briffa (1984) no minimum value is determined to ensure that a chronology is suitable for climatic reconstruction. However, EPS values from 0.909 to 0.992 indicating that each chronology is dominated by coherent stand-level signal (Speer, 2010) hence suitable for river flow reconstruction. Comparing statistical quality of different chronologies is a difficult task if based on SNR (Briffa, 1984). It is mathematically related to EPS with no upper limit.

Similar pointer years, high correlation, higher values of mean sensitivity, lower amount of auto-correlation, higher amount of EPS and Rbar values indicated that these chronologies have a high potential for further investigation *i.e.* dendrohydrology. However, for better cross-dating beyond 1800AD, sample size should be increased for some species.

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