

Millennia-long dendroclimatic records from the Pamir-Alay Mountains (Tajikistan) - perspectives and limitations

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Introduction

To improve our understanding of past climate variability over the globe, the development of new tree-ring climate proxies is crucial. Millennial long records are especially important, as they are quite rare, despite the significant progress in high resolution paleoclimatology made in the last decade (Jones et al. 2009, Esper et al. 2016). One of the best sources of high-resolution paleoclimatic information are tree rings. Dendroclimatological studies from High Asia are of special interest due to immense potential for developing millennia long climate records. However, the response of trees to climate can show high spatial variability which is often not completely understood. Furthermore, despite the fact that a number of tree-ring studies have been carried out in the Himalayas (e.g. Cook et al. 2003, Yadav et al. 2011, Krusic et al. 2015), Karakoram (e.g. Esper et al. 2002, Ahmed et al. 2010), Tien Shan (e.g. Esper et al. 2002) and Tibetan Plateau (e.g. Bräuning et al. 2001, Gou et al. 2014), the Pamirs region remains a research gap. The dendroclimatological potential of the Pamir-Alay region was recently investigated by Opała et al. (2013, 2016, 2017) and Seim et al. (2016). The lack of tree-ring records from Pamir Mountains was due to several reasons, among which restricted access caused by Civil war operations, logistical difficulties, and the scattered spatial distribution of old-growth forest ecosystems should be mentioned.

In this study we investigate tree-ring material from the semi-arid high mountain area of Pamir-Alay to assess its potential for the reconstruction of climatic changes over the last millennium. We also address limitations of dendroclimatological research in Tajikistan, which are connected with high-seismicity of the whole Pamirs region and human activity.

Materials and methods

Studied sites and wood material

The study area is located in the western Pamir mountain system (Fig. 1A) in Central Asia. The study area has a typical high-mountain relief characterized by steep slopes (Fig. 1B) and deep valleys shaped by glacial processes. The highest parts of the mountains are glaciated. The western Pamir-Alay, surrounded by the Kyzyl-Kum desert plains, has a typical arid continental climate. The mean annual total precipitation is 271.3 mm, and mean annual air temperature is 6.6°C (Iskanderkul Meteorological Station). The most important plant community is formed by *Juniperus semiglobosa* and *Juniperus seravschanica* with a significant participation of shrubs and dwarf shrubs of the genera *Rosa*, *Berberis*, *Ephedra*, *Sorbus* and *Cerasus* (Rahmonov et al. 2016). During the field investigations in 2014 and 2015 about 500 samples of living and relict juniper wood were collected from different sites in western Tajikistan. Investigated sites are located within the elevation transect starting from 2000 m a.s.l. up to the near timberline sites above 3000 m a.s.l. In order to analyse if climatic responses differ among sites, samples were taken from all aspects. Additionally, we collected wood from historical buildings, from a village located in the upper part of the Zarafshan river catchment.

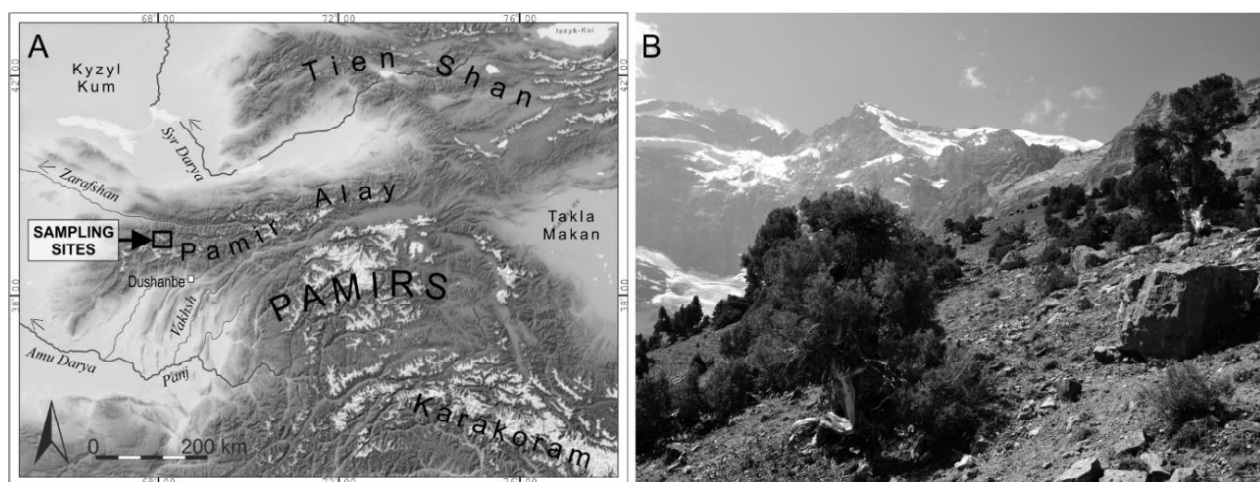


Figure 1: (A) Location of the study area, (B) Examples of old-growth *Juniperus* trees from the western Pamir-Alay.

Methods

Standard 5 mm increment cores were collected from living trees and historical material and taken to the laboratory for processing. Samples were analysed using standard dendrochronological techniques (Stokes & Smiley 1996). Ring widths were measured with a system for automatic recognition of tree rings WinDENDRO (WinDENDRO 2006). Additionally, juniper samples with very narrow rings were re-measured with an optically magnified, stitched image from the system ATRICS based on a high resolution digital video camera attached to a high quality binocular (Levanič 2007). To remove or reduce non-climatic influences, measured ring-width series were detrended with negative exponential curves using ARSTAN software. The individual index series were combined into chronologies by calculating a bi-weight robust means. Cluster analysis was used as technique for grouping the RES site chronologies based on the similarity degree.

For identification of dendroclimatic signal correlation analysis between tree-ring widths and climatic factors was calculated on a 'dendroclimatic year' (from June of the previous growing season to August of the current growing season) (Cook & Kairiukstis 1990). Meteorological data (temperature and precipitation) from weather station Anzob Pass (3373 m a.s.l.) was used in the analysis.

The Pamir region seismicity was received for the period 1900-2014 from available on-line seismic catalogues (ANSS ComCat 2016, Storchak et al. 2013). The earthquakes, which were taken into account in this study, have occurred in a radius within c.200 km of the sampling place.

Results and discussion

Perspectives: tree-ring chronology development

The general descriptive statistics of eight developed tree-ring width chronologies along with their sample depths are shown in table 1 and figure 2. Data from two sites were already analysed and presented by Opala et al. 2017. The other six newly constructed chronologies allow for more comprehensive dendrochronological and dendroclimatological analysis for different altitudes. All chronologies exceed 200 years and the longest ones were developed for the highest locations (site 01, 02 and 03).

The oldest tree, found at the Kulikalon glacier site, is 1311 year old. However, this specimen is not included into the local chronology due to poor correlation with the respective master series. In addition to our recent findings, there is much greater potential for developing long-term tree-ring chronologies based on surrounding trees and other sites, which will be the subject of further study during the next Pamir expedition. Preliminary studies also indicated a great potential of historical wood from this region. Dating of wood samples revealed that historical wood comes from different time periods (Fig. 2). These materials are especially important for the development of millennial

chronologies. Part of timber samples were dated back to the period of 11th-13th centuries, thus it will be possible to improve the statistical properties of the early part of the living trees' regional chronology.

Table 1: Characteristics of juniper tree-ring chronologies from eight sites in the Pamir-Alay Mountains, Tajikistan. TRW = tree ring width

Code	Name	Elevation (m a.s.l.)	No of cores*	Span (length)	Mean segment length	Correlation with master chronology	Mean TRW
01	Kulikalon timberline	3000	17	1005-2014 (1010)	428	.517	0.33
02	Kulikalon glacier	2900	15	1117-2015 (899)	610	.493	0.29
03	Kulikalon plateau	2800	20	900-2014 (1115)	583	.485	0.29
04	Kulikuczurak	2550	17	1597-2014 (418)	205	.560	0.66
05	Isputa	2500	15	1770-2014 (245)	134	.549	1.01
06	Base camp	2300	20	1796-2014 (218)	124	.536	0.98
07	Iguroz	2250	20	1795-2014 (219)	103	.598	1.47
08	Archa Maydan	2200	15	1345-2015 (670)	418	.520	0.49

*Number of cores which were included to the site chronology

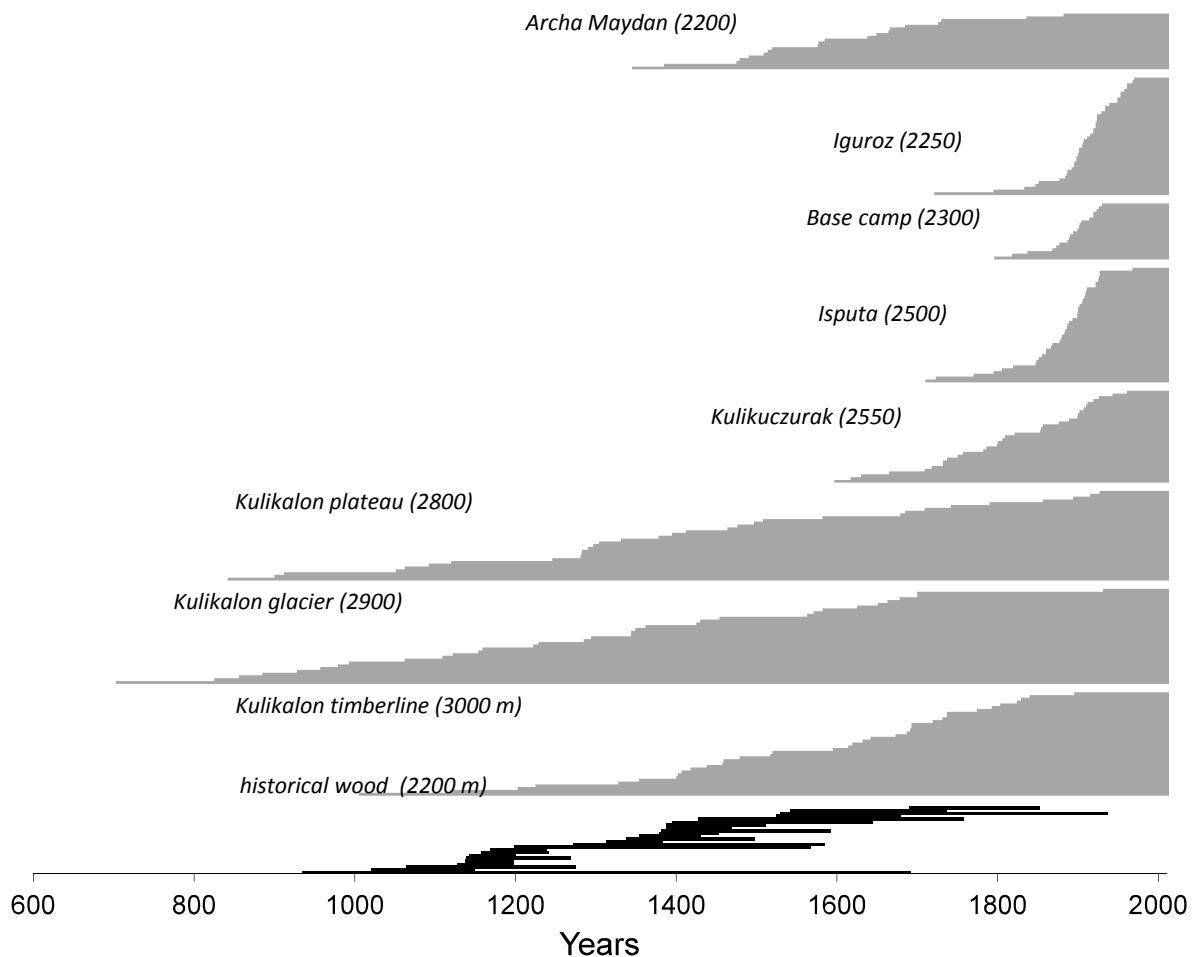


Figure 2: Bar graph showing the time spans covered by the individual measurement series ordered by sites.

Cluster analysis of chronologies using the growth index as variables showed the degree of similarity among site chronologies (Fig. 3). The chronologies of trees from the highest located sites (Kulikalon 01, 02 and 03) were the most similar to each other. Also the similarity between

chronologies from sites: Iguroz, Base Camp, and Kulikuczurak was relatively high. The chronologies from Isputa and Archa Maydan sites were least similar to chronologies from the remaining sites.

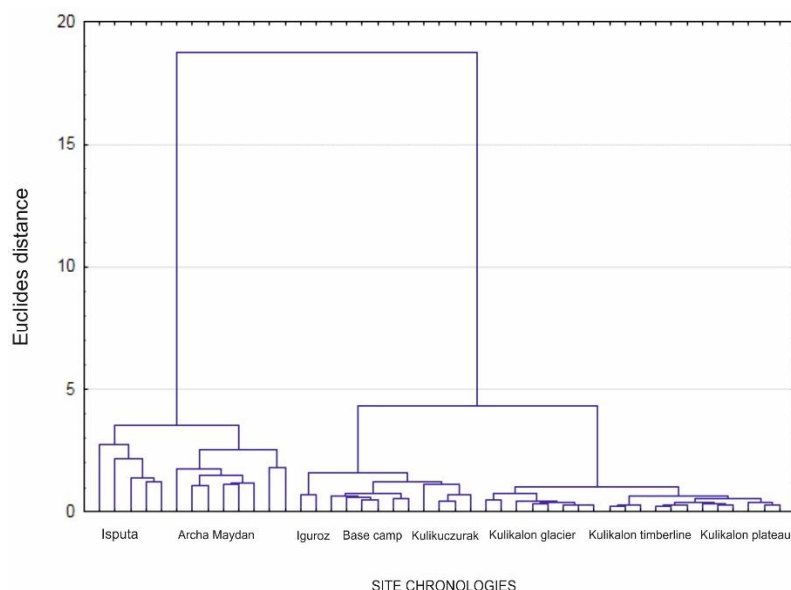


Figure 3: Hierarchical clustering dendrogram of tree-ring chronologies from eight sampling sites over the common period 1900-2014.

Perspectives: climatic signals

In general, trees from the Pamir-Alay did not contain a strong temperature signal, however tree rings from site 02 revealed significant correlations with June and July-August temperatures. In most months the correlations to temperatures were not statistically significant (Tab. 2). The ring-width chronologies were generally positively correlated to winter precipitation and cold month temperatures, especially at the highest elevations (Tab. 3). Very strong correlations were observed between DJF temperatures and the Kulikalon plateau tree-ring width chronology ($r=0.78$). Hence, moisture availability is the major determinant of tree growth, while temperature plays an indirect role in tree growth by modulating the soil moisture via snowmelt and evaporation (Opala et al. 2017). At the lower locations, summer precipitation and summer temperature seem to be the most important factors determining ring formation. The effect of temperature is inverse, indicating drought stress as growth-limiting factor, since high temperatures during June and July can cause soil moisture deficit. At all sites, significant positive relationships were observed with annual precipitation.

Table 2: Correlation coefficients between site tree-ring-width chronologies and the mean temperature from previous June to current August and for different seasons during period 1946-1993. Bold indicate values at the 95% confidence level.

Site	pJun	pJul	pAug	pSep	pOct	pNov	pDec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	DJF	pJ-Aug
01	0,22	-0,06	0,20	-0,22	-0,06	0,41	-0,11	-0,24	-0,13	0,24	0,07	0,05	0,35	0,07	0,13	0,12	0,18
02	0,17	0,01	0,20	-0,14	0,06	0,40	-0,12	-0,16	-0,13	-0,01	0,13	0,25	0,25	0,38	0,32	0,42	0,43
03	0,25	0,29	0,20	0,07	0,06	0,32	0,34	0,06	-0,17	0,08	0,02	0,14	0,20	0,17	0,15	0,20	0,23
04	0,24	-0,21	-0,03	-0,45	0,09	0,02	0,35	-0,13	-0,05	-0,16	0,12	0,22	0,27	-0,08	0,19	0,06	0,20
05	0,03	-0,10	0,07	-0,07	-0,02	-0,03	0,34	0,09	0,21	-0,06	0,00	0,17	-0,01	0,05	0,17	0,13	0,14
06	-0,08	-0,27	-0,10	-0,12	0,06	-0,32	0,41	-0,05	-0,03	0,14	-0,01	-0,08	-0,16	-0,30	0,06	-0,15	-0,17
07	0,10	-0,18	-0,10	-0,19	-0,02	-0,19	0,47	0,10	0,01	-0,03	-0,13	-0,19	-0,30	-0,34	-0,05	-0,28	-0,29
08	0,07	-0,38	-0,11	-0,05	0,05	0,11	0,35	-0,01	0,14	-0,06	-0,01	0,04	0,00	-0,12	-0,03	-0,10	-0,02

Table 3: Correlation coefficients between site tree-ring-width chronologies and the precipitation totals from previous June to current August and for different seasons during period 1946-1993. Bold indicate values at the 95% confidence level.

Site	pJun	pJul	pAug	pSep	pOct	pNov	pDec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	DJF	pJ-Aug
01	0,03	0,23	0,02	0,46	0,33	0,31	0,58	0,62	0,49	0,32	0,22	0,22	0,05	0,10	-0,11	0,71	0,62
02	-0,02	0,09	0,00	0,20	0,11	0,21	0,57	0,53	0,41	0,36	-0,03	0,29	0,20	-0,12	-0,11	0,63	0,45
03	-0,09	0,09	0,08	0,35	0,20	0,49	0,68	0,62	0,59	0,47	0,28	0,30	0,07	0,04	0,02	0,78	0,64
04	0,05	0,14	-0,06	0,50	0,36	0,25	0,45	0,41	0,15	0,29	0,18	0,06	0,11	0,29	-0,07	0,47	0,52
05	0,31	0,05	-0,06	0,16	0,30	0,29	0,22	0,22	0,06	0,07	0,10	-0,06	0,19	0,16	-0,01	0,23	0,33
06	0,20	-0,10	-0,17	0,12	0,33	0,20	0,19	0,21	-0,08	0,11	0,26	0,10	0,35	0,34	0,07	0,15	0,39
07	0,14	-0,20	-0,13	0,19	0,20	0,20	0,13	0,22	0,05	0,05	0,29	0,10	0,33	0,30	0,06	0,18	0,34
08	0,32	0,13	-0,06	0,23	0,19	0,19	0,31	0,16	0,10	0,16	0,11	0,02	0,31	0,31	0,03	0,24	0,39

Limitations: earthquakes & mass movements

Seismic and neo-tectonics studies pointed out that the Pamir region moves northward *en-bloc* and collides with the Tien Shan, which is reflected by high seismicity along this frontal Pamir thrust system and the Main Alay thrust system (Schurr et al. 2014). Seismic shaking influenced growth anomalies in two of our study sites: Archa Maydan and Isputa. These perturbations occurred because the roots of the trees growing in the unstable area were disturbed by sliding and creeping during or shortly after the earthquake event (Owczarek et al. 2017). Hierarchical clustering dendrogram showed that these two sites are characterized by lower similarity to other sites. Also, climatic signals in the ring-width chronologies are weaker. Most of the analysed sequences showed periods of non-climatic reductions of growth and recovery within an individual tree-ring series during the 1900-2014 period (Fig. 4). However, the duration and intensity of these signals vary between individuals. These growth reductions can be recorded immediately after the earthquake or in the following year depending on the time of the event occurrence (before, during, or after the vegetation season). During the 20th century only few earthquake events that are well known from instrumental measurements could be identified in tree-ring data by growth suppressions, e.g.: 1923 and 1924 (of 6.5 M and 6.2 M), 1943 (6.3 M), 1949 (7.5 M), 1955 (5.7 M), and 1999 (5.2 M) (Owczarek et al. 2017). Assuming that the seismic events are an important factor influencing tree growth in unstable areas, and that such impact may mask climatic signal in the

tree-ring series, one must take such uncertainties into consideration when undertaking dendroclimatic reconstruction efforts.

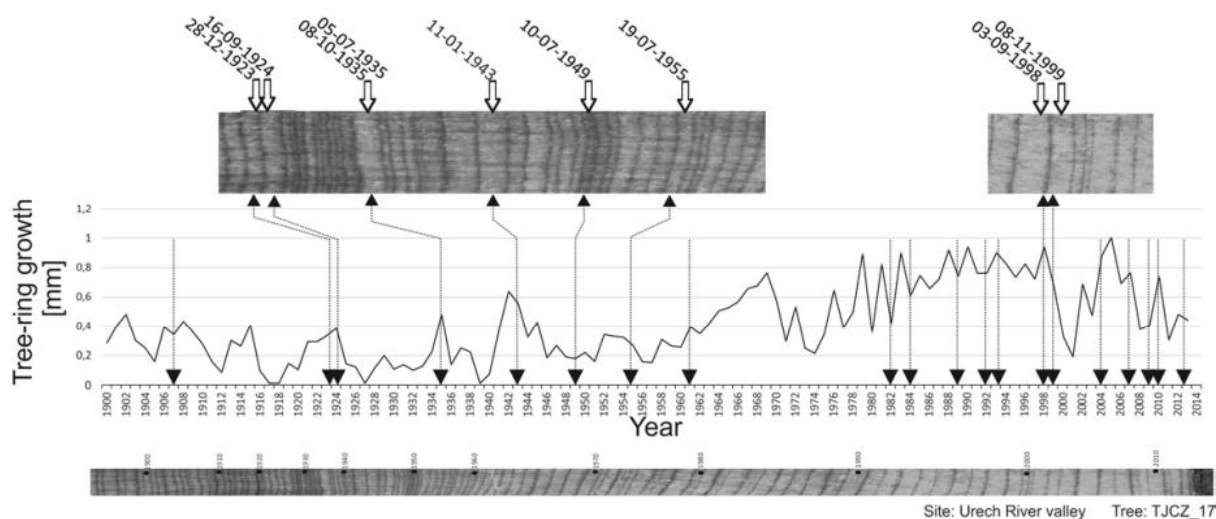


Figure 4: The impact of earthquakes found in an individual tree-ring sequence, visible as a growth suppression occurring in the year of the earthquake or in the first or second following years.

Limitations: human impact

Another limitation in the development of millennial-long chronologies is the impact of human activity. At the lower locations, close to the villages, the traces of wood harvesting like tree stumps or traces of cut branches can be found (Fig. 5 A). Obtaining pieces of living tree trunks with axes affect the course of the tree-ring sequences and cause inconsistencies of individual growth curves with the local tree-ring chronology. We found positive correlations between tree age and elevation (Fig. 5 B), indicating that the average tree age is increasing with elevation. This relationship is connected with timber harvesting in the vicinity of settlements, that lasts already for many centuries.

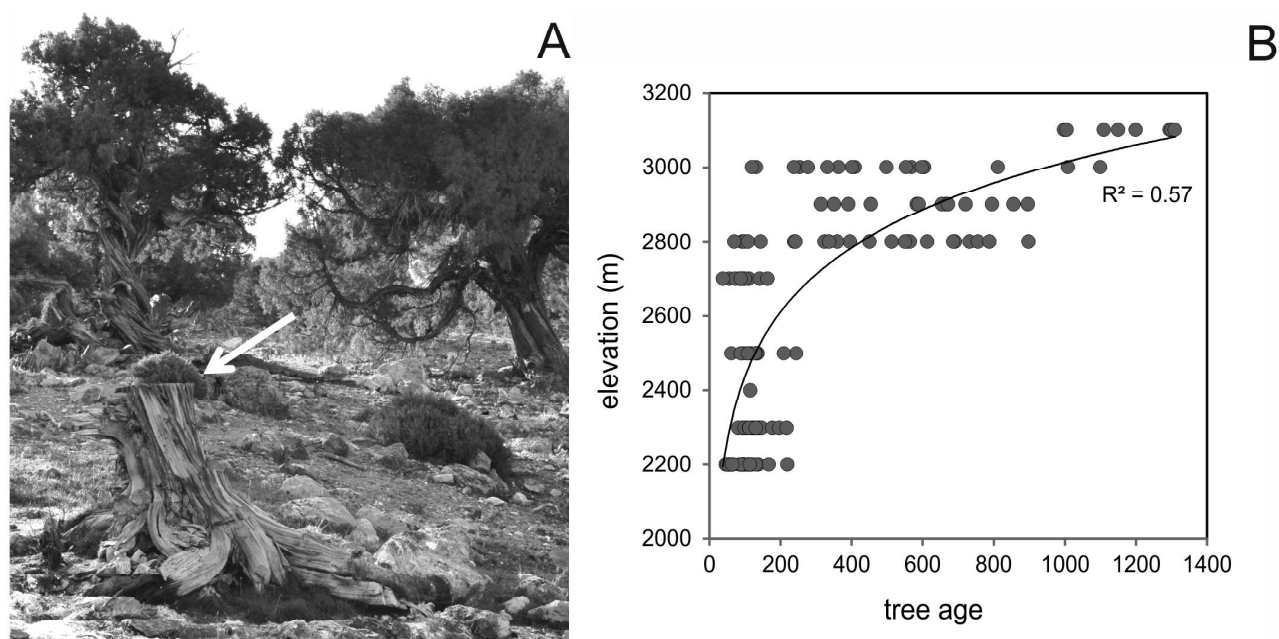


Figure 5: (A) Example of a snag resulting from wood harvesting, (B) Relation between the age of sampled juniper trees and altitude. The average tree age increased with altitude ($R^2 = 0.57$).

Conclusions

Our results demonstrated the great potential of Himalayan pencil juniper *Juniperus semiglobosa* ring-width data for developing multi centennial climate reconstructions for the Pamir-Alay region. The response of tree growth to climate shows that the collected material can serve as a valuable regional archive of past winter precipitation variations for the last 1000 years. Furthermore, the relict material can potentially improve the quality of the early part of these time series. Herein we also discuss the potential limitations for using juniper tree-ring width data from some sites. This is especially important for geologically unstable areas, where the possible impact of climate can be overshadowed by effects of earthquakes and mass movements on tree growth.

The newly developed proxy records can serve as important supplements for a regional tree-ring network in the Central Asia. Therefore, the tree-ring width data from our study will be available to the International Tree-Ring Data Bank for network analysis of pre-instrumental climate patterns in Central Asia. Future field campaigns in this region will enable the development of regional, dense networks of chronologies covering larger areas of the Pamir mountain system which are insufficiently investigated so far. The presented perspectives and limitations of dendroclimatological studies in Tajikistan indicate that it will be possible to bridge the research gap in the existing centuries long hydroclimatic reconstructions for Central Asia.

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