APPLICATION OF TREE-RING RESEARCH IN PAKISTAN

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Introduction

The study of tree-rings or dendrochronology, is the scientific method of dating based on the analysis of growth-ring patterns from trees (http://en.wikipedia.org/ wiki/). Dendrochronology can date the time at which tree-rings were formed, in many types of wood, to the exact calendar year. This field of research has rapidly expanded over the last 30 years not only in terms of the number of sample locations but also in the analysis methods and the range of applications. A major strength of the research field has been the open sharing of data with the best example of this being the development of the International Tree-Ring Data Bank (ITRDB; http:// www.ngdc.noaa.gov/paleo/treering.html). Currently, the ITRDB contains over 3,200 tree-ring chronologies from over 1,500 sites around the world representing over 100 tree and shrub species. Anybody can visit the website and obtain the data. The rapid growth of research has led to many different applications and a brief over-view of some of them thought to be relevant to Pakistan is presented (Table 1). We will not be providing an introduction to the specific techniques involved since this is another separate exercise (see Fritts 1976; Baillie 1995; Cook & Kairiukstis 1992).

Only a limited amount of tree-ring research has so far been conducted in Pakistan and all of it has been based on conifer species. The starting point was an introductory paper by Ahmed (1987). Ahmad (1988) mentioned the problems encountered with tree age estimation. Subsequent papers present initial *Abies pindrow* tree-ring chronologies from a moist temperate region (Ahmed, 1989) and then switch to a focus on population dynamics of *Juniper excelsa* and *Pinus gerardiana* in dry temperate areas (Ahmed *et al*., 1990a; 1990b; 1991). Ahmed and Sarangzai (1991 a,b) estimated age and growth rates of various conifer species. The first international publication into the climate potential from the tree-rings was published by Esper *et al*. (1995) based on *Juniper excelsa*. The same species was subsequently used to determine long-term tree-ring variations (Esper, 2000) and ultimately led to the millennial precipitation reconstruction based on tree-ring oxygen-isotope concentrations (Treydte *et al*., 2006). Ahmed and Naqvi (2005) have presented four tree-ring chronologies of *Picea smithiana* from various climatic zones. Recently, Ahmed *et al*. (2006) investigated the phytosociology and structure of forests from different climatic zones. Recently, Khan *et al*. (2008) looked at the potential of *Picea smithiana* from a site in neighbouring Afghanistan and Ahmed *et al*. (2009 a,b) presented preliminary climatic response functions from the same species in Pakistan.

A network of 28 tree-ring sites has recently been compiled for dendroclimatic studies (Figure 1, Table 2; Ahmed *et al*., 2010). The sites were all from northern Pakistan and consisted of six species from five genera – *Abies pindrow* (Royle ex D. Don) Royle (West Himalayan fir, ABPI), *Cedrus deodara* (D. Don) G. Don (Himalayan cedar, CDDE), *Juniperus excelsa* M. Bieb. (Greek juniper, JUEX), *Picea smithiana* (Wall.) Boiss. (West Himalayan spruce, PISM), *Pinus wallichiana* A.B. Jacks (Himalayan blue pine, PIWA) and *P. gerardiana* Wall. ex D. Don. (Chilgoza pine, PIGE). Species codes follow the general convention listed on the International Tree-Ring Data Bank - ITRDB (Grissino-Mayer, 1993).

Dendroecology: The recent focus for most dendrochronological studies is climate reconstruction and this often sadly means the investigation of general ecological parameters gets overlooked. Basic information such as the growth-rate of the trees and their longevity is not being incorporated into forest management training that is still directed towards only the size of trees, not their age.

One important consideration for dendroecological studies is the potential age of the trees. Table 2 shows several species had trees attaining ages of around 700 years (*Cedrus deodara*, *Pinus gerardiana, P. wallichiana* and *Picea smithiana*) and older ages possible as indicated by studies of the same species from India (e.g., Singh *et al*., 2004; Singh and Yadav, 2007). The earlier collections of juniper (Esper *et al*., 1995) were the oldest so far from Pakistan, with some trees significantly greater than a 1,000 years and no other species seems likely to match this. By simply using the mean ring-width values measured for each site, the required number of years for a tree to reach 30 cm in diameter is indicated in Table 2. A size of 30 cm was chosen, as this is often the generally accepted minimum for possible utilisation (i.e., logging). The results in Table 2 demonstrate the wide range of times required to attain this size even within same species (e.g. 30cm Greek juniper trees could be anything between 98 and 536 years old – a five fold age range!). Our main point from this is to highlight that size does not reflect age. We have found this to be true between different stands of the same species (as shown here in Table 2) and even within the stands themselves. Without detailed information about the growth rates of the trees any management is severely limited. Such information helps provide a focus for conservation efforts, an understanding of species population dynamics and a realistic understanding of the likely "recovery time" for any reforestation. The extensive range of growth-rates underpins the need for **local** information for effective management. Having trees known to be over 1,000 years old will draw tourists (national and international) to an area.

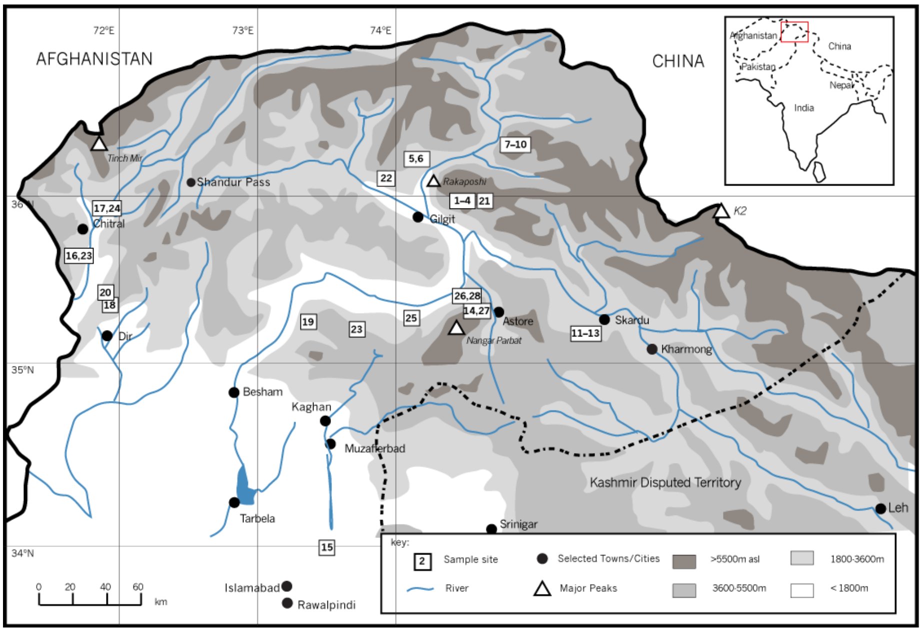

Fig. 1. Map of northern Pakistan showing the location of the tree-ring sites (sample details provided in Table2) (redrawn from Ahmed *et al*. 2011).

Table 1. Definitions of the main subfields of dendrochronological research described in this article (source: Kaennel & Schweingruber 1995). A key reference has been included as a starting point for the interested reader to obtain further information.

Term	Explanation / Definition	Key Reference
Dendroarchaeology	System of scientific methods used to determine the exact time span of a period during which timber has been felled, transported, processed and used for construction.	Stahle *et al*. (1985)
Dendroclimatology	The use of dated tree-rings to reconstruct and study past and present climates.	Briffa *et al*. (1990)
Dendroecology	The use of dated tree-rings to study ecological problems and the environment (e.g. forest stand dynamics).	Fritts & Swetnam (1989)
Dendrohydrology	The use of dated tree-rings to study and date hydrologic phenomena such as river flow, lake level changes and flooding history.	Cook & Jacoby (1983)
Dendroglaciology	The use of dated tree-rings to study and date past glacier movements.	Luckman (1994)
Dendroseismology	The use of dated tree-rings to study and date earthquakes.	Jacoby (1997)

Dendroclimatology: The recent survey of 6 conifer species in northern Pakistan by Ahmed *et al*. (2010) found the best prospects for climate reconstructions to be *Cedrus deodara* and *Pinus gerardiana* and the result is consistent with studies from neighbouring India. The comparison to climate data was strongest from the same two species though *Picea smithiana* at one site was also highly significant. A general climate correlation pattern from all species was evident that starts with a strong negative relationship to temperature in the previous October, then turns towards positive during winter, before again becoming significantly negative by the current May. The previous October signal is thought to be a lag effect where hot temperatures (and low soil-moisture) stress the trees, thereby reducing reserves available for the following spring. Similarly, hot temperatures in late spring (May) lead to greater soil moisture losses and tree transpiration costs. Conversely, there is an extended strong positive precipitation correlation from late winter to spring (January to May). This ends abruptly and there is no evidence of a summer (June-September) monsoon signal seen in the rainfall correlation functions.

Further studies are needed over wider geographical locations (i.e. network development) but there are exciting prospects for multi-species combinations as well as investigating the potential of some hardwood species. The initial results appear very encouraging for climate reconstructions and future results are likely to make an important contribution to regional climate studies.

Dendrohydrology: Pakistan is one of the world's most arid countries, with an average rainfall of under 240 mm per year. 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 "megadroughts"). Elsewhere there is strong archaeological evidence for the destabilizing influence of past droughts on advanced agricultural societies (e.g. USA) – something that should resonate today given the increasing vulnerability of modern water-based systems (both agricultural and hydroelectrical) 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 (2005) 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 states that the science is in its infancy and that there is an inadequate knowledge base. This is where studies from tree-rings can help.

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 full range of past conditions – a widespread problem often faced throughout the world. The solution adopted in several other countries 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. This understanding is not new, but only really over the past decade has the power of tree-ring analysis and its well developed statistical methods been brought to bear on the reconstruction of the joint space-time properties of past climate.

Fortunately, the northern area of Pakistan has forests containing a range of species (Ahmed *et al*, 2011) that we now know can provide long annual tree-ring chronologies thanks to the pioneering research. Recently a program of study is the (PakUS funding) the aims were 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 500 years. This 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. These results also hope to provide important information to wider regional studies on the Asian Monsoon system thereby raising the international profile of Pakistan.

Dendroarchaeology: Pakistan has a rich history in archaeology with several internationally significant sites such as Taxila, Harappa and Moenjodaro. Tree-ring dating techniques have potential applications with archaeological wooden carvings and structural timbers (e.g. on temples, houses, graves). Not only can the tree species be identified but the ring sequences could be dated. This, however, will only be possible after the practical considerations of optimal chronological coverage in both geographical and temporal dimensions.

The interactions between archaeology and dendrochronology becomes more limited as we extend further back in time. As pointed out by Baillie (2002), for the last millennium dendrochronological coverage is so extensive that high levels of dating success are now possible. In this period, historical documentation is normally at chronological resolution, with the result that dendrochronology acts to refine chronology and is unlikely to uncover major lapses in historical/archaeological chronology. However opportunities exist to add considerably to the environmental background within which human populations operated. This enhanced environmental knowledge can come from studies of the tree-ring chronologies themselves both at a local level and at a hemispheric scale. Baillie (2002) calls for the integration of tree-ring derived information, both chronological and environmental, with other well dated information from other proxies to provide archaeologists with the best possible background picture for their studies.

The long history of human activity in the region is also likely to have been an influence on forest distribution. Recent research by Miehe *et al.* (2009) has shown that during the last five millennia, the extensive dwarf shrublands in the region have replaced woodlands and forest. The authors argue that the driving force has

Table 2. A summary of 26 tree-ring chronologies from northern Pakistan (modified from Ahmed *et al.* 2011).

Species Code[1]	Site name & Code[2]	Latitude (N)	Longitude (E)	Elev. (m)	Cores / Trees	MRW[3]	Corr[4]	Max Period (years)	Years to grow 30cm dbh
ABPI	Astore-Rama AST [14]	35° 21’	074° 48’	3,450	28/17	0.92±0.34	0.59	1505-2005 (501)	163
ABPI	Murree-Ayubia MUA [15]	34° 02’	073° 24’	2,550	13/7	1.66±0.97	0.55	1678-2005 (328)	90
CDDE	Bumburet (Kalash) BUK [16]	35° 41’	071° 38’	2,590	19/10	0.97±0.61	0.67	1411-2006 (596)	155
CDDE	Chitral-Gol NP CGP [17]	35° 54’	071° 44’	3,030	27/16	1.57±0.76	0.67	1537-2006 (470)	96
CDDE	Islam Baiky (Dir) ISB [18]	35° 21’	071° 56’	2,660	62/31	1.13±0.59	0.68	1511-2006 (496)	133
CDDE	Mushfar (Gilgit) MSF [19]	35° 30’	074° 05’	2,860	30/15	0.66±0.40	0.90	1296-2007 (712)	227
CDDE	Zairat (Chitral) ZAC [20]	35° 21’	071° 48’	2,900	23/17	1.58±0.79	0.54	1472-2005 (534)	95
PCSM	Chera (Gilgit) CHE [21]	36° 02’	074° 35’	3,110	18/10	1.10±0.57	0.73	1394-2005 (612)	136
PCSM	Naltar (Gilgit) NLT [22]	36° 09’	074° 11’	3,400	35/22	0.83±0.40	0.65	1387-2005 (619)	181
PIGE	Bumburet (Kalash) BUK [23]	35° 41’	071° 38’	2,590	20/11	0.67±0.29	0.67	1403-2006 (604)	224
PIGE	Chitral-Gol NP CGP [24]	35° 54’	071° 44’	3,030	21/11	0.52±0.24	0.59	1260-2006 (747)	288
PIGE	Joti (Chilas) JOT [25]	35° 24’	074° 07’	2,670	28/15	1.06±0.50	0.83	1559-2007 (449)	142
PIGE	Mushkin (Shalguatum) MUS [26]	35° 30’	074° 45’	2,640	18/9	0.92±0.54	0.85	1362-2007 (646)	163
PIWA	Astore-Rama AST [27]	35° 21’	074° 48’	3,450	44/25	0.93±0.61	0.632	1317-2005 (689)	161
PIWA	Mushkin (Shalguatum) MUS [28]	35° 30’	074° 45’	2,750	12/6	1.34±0.76	0.84	1730-2007 (278)	112
JUEX	Bagrot[85] BAG [1-4]	36°02’	074°35’	3,100	31	1.53		1593-1993	98
				3,300	38	0.89		1369-1993	169
				3,050	37	0.99		1438-1993	152
				3,750	25	0.92		1240-1999	163
JUEX	Chaprot[5] CHP [5,6]	36°20’	074°02’	3,500	31	0.49		1032-1993	306
				3,900	18	0.34		1141-1993	442
JUEX	Morkhun[5] MOR [7-10]	36°35’	075°05’	3,900	33	0.37		476-1999	405
				3,900	17	0.31		968-1990	485
				3,800	20	0.33		554-1990	455
				3,400	18	0.35		1069-1990	429
JUEX	Sartap[5] SAT [11-13]	35°10’	075°30’	3,300	14	0.65		1412-1993	231
				3,700	29	0.28		736-1993	536
				3900	28	0.30		388-1993	500

[1] Species codes are *Abies pindrow* (ABPI), *Cedrus deodara* (CDDE), *Juniperus excelsa* (JUEX), *Picea smithiana* (PCSM), *Pinus gerardiana* (PIGE) and *Pinus wallichiana* (PIWA). [2] Only the site code number is shown in Fig. 1. [3]Mean Ring-Width ± standard deviation. [4] Inter-series correlation. [5] Details described in Esper *et al*. 2002, 2007.

been the human presence and grazing pressures resulting in desertification and not triggered by a change in climate (desiccation). This theory needs to be tested and dendrochronology can play a vital role.

Dendroseismology: Everybody is aware that Pakistan is prone to earthquakes because it lies in the collision zone between the Indian tectonic plate to the south and the Eurasian plate in the north. Several recent disasters have heightened global awareness of Pakistan's vulnerability and triggered massive humanitarian relief efforts and other international assistance. In spite of extensive research and sophisticated equipment, it still remains extremely difficult to predict when an earthquake may occur. The best result available is an estimation of the likelihood (i.e. the "risk") of an earthquake occurring in a particular region. Such risk assessment depends on having the past history of events and their magnitudes being known over many centuries of time. Sadly in Pakistan only recent information is available so the risk of future earthquakes in particular regions is unknown. This is where tree-ring studies could provide one method at trying to resolve this problem.

Overseas studies have shown that some trees record in their growth-rings past effects of earthquakes. This means the actual year can be detected and by looking how widespread different trees were affected the extent (=magnitude) can also be determined. The same research methods (i.e. dendroseismology) can be applied to a region that is known to have an earthquake history (e.g. Azad Kashmir). This research would aim to survey potential species for displaying earthquake effects and unlock the history of earthquakes in one region. If proven successful, then a wider coverage could be proposed.

Dendroglaciology: GIS based glacial mapping and mass-balance calculations have provided impressive results (e.g. Seong *et al*. 2009) and form part of a larger programme aimed at implicating future scenarios. The results however all hinge on accurate information about past patterns and local rates of response to changes in climate. This is where tree-rings can help. Investigations of late Holocene history of glacier fluctuations in regions such as Chitral (western) and Karakoram (eastern) valleys could be undertaken by applying a combination of tree-ring research methods such as –

- Determining the ages of trees growing on glacier deposits (i.e. moraines)
- Radiocarbon dating of buried wood material in moraines
- Crossdating the ring patterns of buried trees to those from living stands
- Climate reconstructions using tree-rings and their comparison to those derived from glacial studies.

One current quandary is the conflicting result being reported that some glaciers are defying the global trend of rapid reduction/retreat and are in fact advancing (Owen 2009). One approach might be the dendrochronological sampling of contrasting locations in terms of climate influences to investigate the similarity and synchronicity of past responses to known major cooling events such as the Little Ice Age (LIA). This would provide supporting information to assist efforts attempting to model future outcomes.

The results from such tree-ring studies would considerably strengthen the database for understanding the amount of glacial-water contributing to the upper Indus River system and allow the assessment of trends or periodic variations that are vital for sustainable water management in the region – especially urgent given the pressing need for expanded utilisation.

Conclusion

Tree-ring research has expanded rapidly around the world over the last three decades. Research in Pakistan has only really just started. The rich diversity of tree species found in many areas of the country adds to the potential for dendrochronological studies. A number of different research applications are possible and some of these have been briefly introduced. We believe Pakistan has the potential to make important international contributions to several regional studies (such as climate change, glacial fluctuations and earthquake risks). However, the continued need for fuelwood and rapidly rising population pressures means that deforestation is an ever-present concern. This may limit potential research applications and emphasises the importance of rapid tree-ring network collections and the proper archiving of the samples.

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