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RESEARCH REPORT

TREE-RING CHRONOLOGIES FROM NEPAL

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ABSTRACT

Ten ring-width based chronologies from Nepal are described and the prospects for further dendroclimatic work there reviewed briefly. The initial results are encouraging, and more intensive subregional sampling is called for. All the cores examined showed distinct annual rings, and there was little evidence of double or missing rings, except juniper at some sites and in some *Pinus roxburghii* trees. Difficulty was encountered in dating *Pinus wallichiana* and *Cupressus dumosa.* Individual site chronologies of *Cedrus deodora, P. roxburghii* and *P. wallichiana* were particularly promising, and of high elevation *Abies spectabilis* moderately so. Densitometric data are likely to be more useful for this species. The paucity of meteorological data in Nepal represents an obstacle to further dendroclimatic work there.

INTRODUCTION

A large collection of tree-ring samples representing a wide variety of species and habitats was made in Nepal in 1979-80 by Rudolf Zuber under the general direction of Dr. Fritz Schweingruber of the Swiss Forest Research Center, Birmensdorf. We have developed chronologies for ten of these sites, eight from cores and two from measurements kindly supplied by Dr. Schweingruber. These chronologies add to the growing dendrochronological coverage of southern Asia (Ahmed 1989; Bhattacharyya et al. 1988, 1992; Bilham et al. 1983; Hughes 1992; Hughes and Davies 1987; Jacoby and D'Arrigo 1990; Murphy and Whetton 1989; Pant 1979, 1983, 1984; Pant and Borgaonkar 1983, 1984; Pant et al. 1988; Ramesh et al. 1985, 1989).

NEPAL

The Kingdom of Nepal lies on the southern slopes of the Great Himalaya between India and Tibet. There is an extensive coniferous flora, ranging from subtropical to subalpine conditions. We focus on materials from subalpine and temperate sites. A wide range of climate is found in Nepal (Government of Nepal 1977), with annual precipitation varying from 250 mm (in the west) to 6000 mm (in the east). There is also a strong negative precipitation gradient between central Nepal (the southern slopes of the Annapurna range, for example) and the arid north central region close to the Tibetan border. In general, about 80% of the total precipitation is brought by the summer monsoon during June to September, with October and November usually being the driest months. Winter precipitation increases in significance to the west of Nepal. Snowfall occurs mainly above 3500 meters elevation in the northern and western mountain regions. Maximum temperatures tend to occur during late spring and early summer, ranging from 19 to 27 degrees Celsius at Kathmandu (elevation 1300 m). There are very few meteorological data available for Nepal before 1970, and these are limited to Kathmandu. This presents a serious obstacle to applying dendroclimatological techniques in Nepal.

THE COLLECTIONS

All the materials examined were from temperate or subalpine forests (2500 – 3700 m elevation) with the exception of *Pinus roxburghii* sites in the subtropical zone (1320-2080 m elevation). General site information is given in Table 1 and locations indicated in Figure 1. The cores are now stored in Dr. Schweingruber's laboratory at Birmensdorf. A wide range of ecological conditions is represented in the collections, with the effects of human disturbances such as pruning being evident to some degree at almost all sites. The exceptions are Bhaktapur (BHA), Nagarjun (NAG) and Langtang Gaon (LAG), although natural disturbances produced by fire at Bhaktapur (BHA) and rock falls at Langtang Gaon (LAG) were noted.

Table 1. Tree-ring localities in Nepal.

Site Name	Site Code	Latitude	Longitude	Elevation (meters)	Aspect	Species	Site Chronology
Bhaktapur	BHA	27°40'N	85°25'E	1320	W	*Pinus roxburghii*	-
Chaku Khola	CHA	27°50'N	86°00'E	2750	N	*Tsuga dumosa*	-
Chandan Bari	CHB	28°05'N	85°20'E	3500	N	*Abies spectabilis*	-
Ghorepani	GHO	28°25'N	83°45'E	3220	N	*Abies spectabilis*	*
Giri Gaon	GIG	29°45'N	82°10'E	2500	NE	*Cedrus deodara*	*
Gonga Danda	GON	28°05'N	85°10'E	3300	NW	*Abies spectabilis*	*
Gonga Danda	GON	28°05'N	85°10'E	3250	S	*Tsuga dumosa*	-
Gurchi Lekh	GLH	29°30'N	82°05'E	3450	N	*Abies spectabilis*	*
Hunbato	HUT	28°35'N	84°15'E	2750	S	*Picea smithiana*	-
Juri Thumki	JUT	27°40'N	86°05'E	2900	SE	*Tsuga dumosa*	-
Kalingchok	KAC	27°45'N	86°05'E	3720	NW	*Abies spectabilis*	*
Lamjura	LAM	27°35'N	86°30'E	3100	N	*Abies spectabilis*	-
Langtang Gaon	LAG	28°10'N	85°30'E	3700	N	*Larix potanini*	-
Langtang Khola	LAN	28°10'N	85°30'E	3100	N	*Tsuga dumosa*	*
Marming	MRM	27°50'N	86°00'E	3020	NW	*Abies spectabilis*	-
Marsyangdi Khola	MAR	28°35'N	84°15'E	2900	SW	*Abies spectabilis*	*
Nagarjun	NAG	27°45'N	85°15'E	1520	W	*Pinus roxburghii*	-
Pisang	PSN	28°35'N	84°10'E	3200	N	*Juniperus recurva*	-
Pisang	PSN	28°35'N	84°15'E	3000	E	*Abies spectabilis*	*
Rara Gaon	RAG	29°35'N	82°05'E	3000	S	*Picea smithiana*	-
Rara Lake	RAL	29°30'N	82°05'E	2950	N	*Juniperus recurva*	-
Rara National Park	RAP	29°30'N	82°05'E	3050	N	*Pinus wallichiana*	*
Rupchet	RPC	28°05'N	85°10'E	3620	SE	*Juniperus recurva*	-
Tila Nala	TLN	29°05'N	81°50'E	2080	NE	*Pinus roxburghii*	*
Tragdobuk	TRB	27°25'N	86°35'E	2950	NE	*Tsuga dumosa*	-

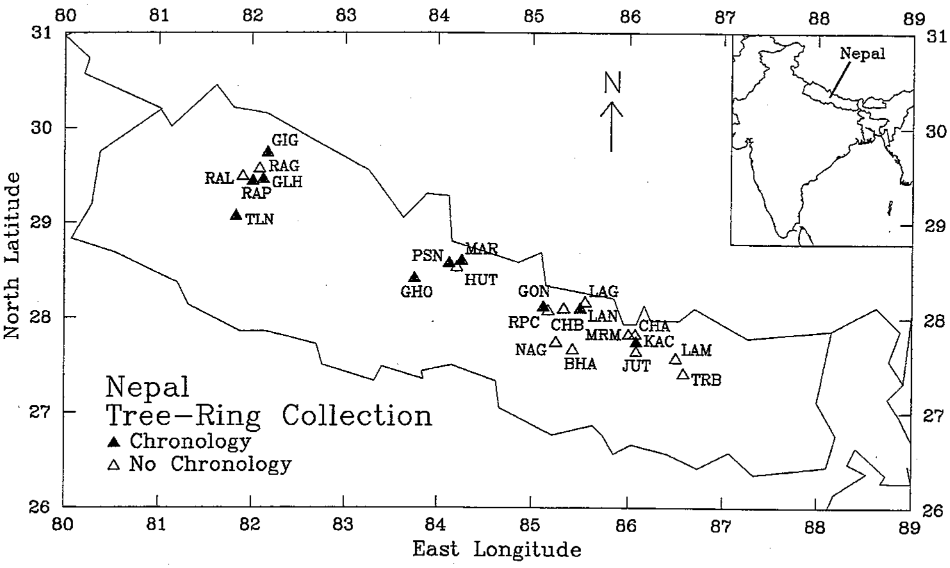

Figure 1. Location of sites collected and of chronologies developed. Solid triangles indicate sites from which ring chronologies were developed; open triangles denote sites that did not produce chronologies. A key to the three-letter site codes is given in Table 1.

DATING

The eight collections deemed most promising on the basis of length and apparent sensitivity were dated and analyzed (in Tucson) prior to the development of chronologies. Material from two sites (Ghorepani [GHO] and Kalingchok [KAC]) had already been analyzed densitometrically in Dr. Schweingruber's laboratory. The selection of potential trees for tree-ring research from a new area depends on the availability of trees with datable and climate-sensitive annual ring sequences. All the tree cores analyzed from Nepal have clear annual rings with distinct ring boundaries. In some species, the boundary between earlywood and latewood is also very clear. It could be of value to explore variables such as earlywood and latewood widths in such cases as potential sources of climate information. This applies to *Pinus roxburghii, Larix potanini,* and some annual rings of *Cedrus deodara.*

Except for juniper at some sites and some trees of *Pinus roxburghii*, the problem of dating tree-ring sequences due to the presence of double or missing rings is small. Extensive use has been made of crossdating techniques based on the skeleton plot method to find out whether crossdating existed between cores from the same tree, between cores of the same species on the same site, between species growing on different sites, and between different species growing on different sites. The present study reveals that, except for junipers growing in Pisang (PSN) and a few cores from other sites, there is crossdating between two cores collected from the same tree, between the same species growing in the same site, and even between different species at the same site and some cores between different species growing on different sites. However, dating of *Pinus wallichiana* and *Cupressus dumosa* was problematical. The samples examined from these species did not crossdate well, primarily due to strong serial persistence in the tree-ring series. In *Cupressus* there are often long series of microrings, and dating is complicated by the lack of variation in these suppressed zones. There may be a ten-

Table 2. Sample statistics (residual chronologies) for 10 Nepalese sites based on common period 1901-1970.

Site	Trees (cores)	1	2	3	4	5	6	7
TLN	11(20)	0.42	0.41	0.68	7.67	5	0.88	45.9
GLH	9(18)	0.21	0.19	0.44	2.14	6	0.68	25.9
RAP	15(28)	0.31	0.31	0.50	6.77	7	0.87	35.3
GIG	16(25)	0.66	0.65	0.82	29.78	3	0.97	67.3
GHO	11(17)	0.40	0.39	0.63	7.11	5	0.88	44.4
MAR	10(20)	0.41	0.40	0.63	6.57	5	0.87	45.0
PSN	13(24)	0.31	0.31	0.53	5.71	6	0.85	34.9
GON	14(26)	0.43	0.43	0.60	10.39	5	0.91	46.4
LAN	14(25)	0.32	0.32	0.51	6.46	7	0.87	35.8
KAC	9(13)	0.27	0.26	0.46	3.16	6	0.76	33.2

1: Mean correlation among all radii
2: Mean correlation within trees
3: Mean correlation between trees
4: Signal-to-noise ratio
5: Number of trees to produce subsample signal strength > 0.85
6: Expressed population signal
7: Percentage of variance in the first eigenvector

Table 3. ARSTAN chronology statistics for 10 Nepalese sites.

Site	Period	Tree (Cores)	1	2	3	4	5
TLN	1683-1979	14(28)	0.51	1727	0.19	0.26	0.59
GLH	1695-1978	11(22)	0.00	1756	0.10	0.17	0.70
RAP	1729-1978	15(30)	0.00	1780	0.13	0.17	0.44
GIG	1714-1978	18(36)	0.24	1730	0.28	0.27	0.21
GHO	1740-1978	14(25)	0.00	1846	0.20	0.26	0.55
MAR	1607-1978	10(20)	0.08	1641	0.18	0.20	0.40
PSN	1796-1978	14(28)	0.00	1829	0.13	0.18	0.55
GON	1735-1978	14(27)	0.16	1827	0.16	0.20	0.44
LAN	1569-1978	14(26)	0.24	1595	0.12	0.16	0.53
KAC	1725-1978	13(30)	0.02	1737	0.12	0.21	0.65

1: Percentage of missing rings
2: The first year in which there were enough trees to give subsample signal strength >0.85
3: Mean sensitivity
4: Standard deviation
5: First-order autocorrelation

dency for missing rings to be more prevalent at lower elevations (Table 3). Thus their occurrence is more common in *Pinus roxburghii* growing at Tila Nala (TLN) and *Cedrus deodara* at Giri Gaon (GIG) but rare in trees of *Pinus wallichiana, Abies spectabilis*, and *Picea smithiana*. In general, intra-annular bands or double rings were very rare in all species studied. Where present, they are clearly distinguishable by their faint boundary. However, in *Cedrus deodara* dark bands of traumatic cells within the earlywood cells of some rings superficially resemble latewood. As these features did not cross match among trees, they can be readily distinguished by crossdating techniques and careful microscopic examination.

The crossdating of each site chronology was repeated independently by a second dendrochronologist as the first stage of quality control. The ring widths were measured to

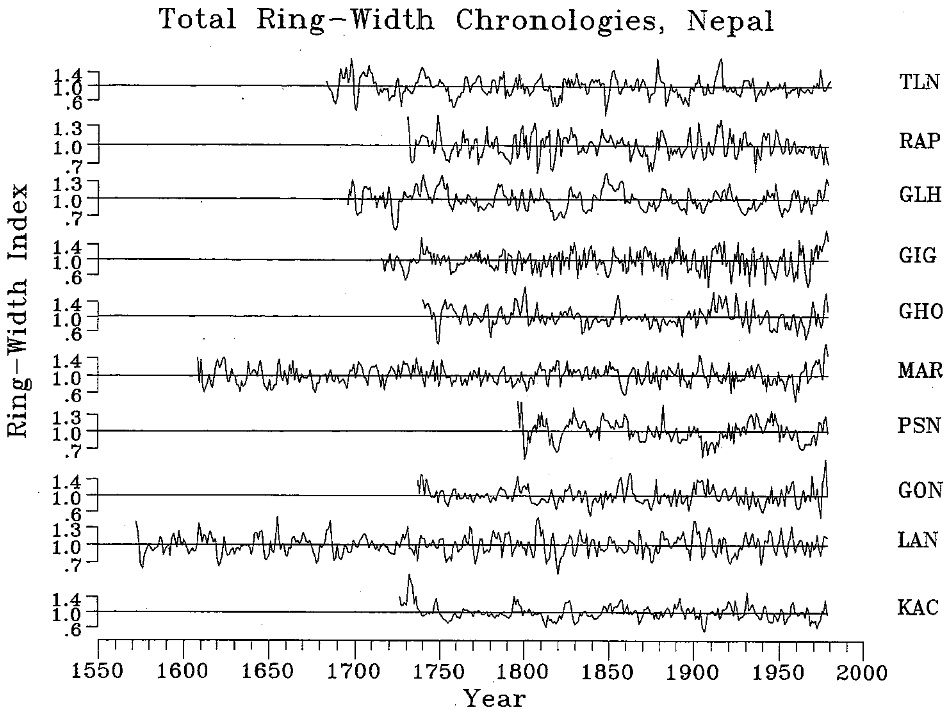

Figure 2. Ring width chronologies for ten Nepal collections arranged from west (top) to east (bottom). These are the "ARSTAN" chronologies whose derivation is described in the text. A key to the site codes is given in Table 1.

0.01mm using a Henson incremental measuring machine linked to a microcomputer, in the case of the eight sites analyzed in Tucson. A further check on the quality of measurement and dating for all ten chronologies was then carried out using program COFECHA (Holmes et al. 1986), which uses the ring-width measurement series to help identify segments of a core, cores, or groups of cores where dating or measurement errors or unacceptable ambiguities might exist. If such problems could not be resolved, usually by reference to the original cores, the material in question was excluded from further analysis.

CHRONOLOGIES

The ring-width series of each core was then transformed to ring-width indices using the program ARSTAN developed by E. R. Cook (Cook 1985; Holmes et al. 1986). In this case each core series was detrended using a spline, each series was prewhitened using an autoregressive model, the series for each chronology were combined using a biweight mean (this produces the 'residual chronology'), and the series were rereddened using the pooled time-series model of the cores for that site (producing the 'ARSTAN chronology'). In the case of

Table 4. Correlations between residual chronologies A.D. 1798-1978 (n=181), p>0.02 shown bold. See Table 1 for three-digit site codes.

	TLN	GLH	RAP	GIG	GHO	MAR	PSN	GON	LAN	KAC
TLN	1.00	-.04	**0.31**	**0.27**	0.04	0.11	0.16	-.04	0.06	0.03
GLH	-	1.00	**0.28**	-.08	0.19	0.18	**0.26**	**0.31**	0.08	**0.39**
RAP	-	-	1.00	-.06	0.01	0.06	**0.27**	-.06	-.16	0.06
GIG	-	-	-	1.00	0.13	**0.24**	-.09	0.03	-.01	-.07
GHO	-	-	-	-	1.00	**0.24**	0.01	**0.42**	0.22	**0.27**
MAR	-	-	-	-	-	1.00	0.20	0.16	0.21	0.09
PSN	-	-	-	-	-	-	1.00	-.01	-.03	0.10
GON	-	-	-	-	-	-	-	1.00	0.22	**0.27**
LAN	-	-	-	-	-	-	-	-	1.00	0.20
KAC	-	-	-	-	-	-	-	-	-	1.00

the two sites with the longest cores, Marsyangdi Khola (MAR) and Langtang Khola (LAN), splines with 50% variance reduction functions (VRFs) at 200 years were used. For all other sites, splines with 50% VRFs at 120 years were used. The results of this chronology building process are given in Tables 2 and 3 and Figure 2. Table 2 refers to the residual chronologies as it deals primarily with correlations between series. Table 3 gives statistics of the ARSTAN chronologies, since these are designed to provide an optimal representation of the interannual variability of the sampled trees at each site. It is clear that much the strongest common signal between trees is found in the deodars (*Cedrus deodara*) of Giri Gaon (GIG). This chronology also has the highest values for mean sensitivity and standard deviation and the smallest first-order autocorrelation. It is of interest that the site is on a very steep northeast facing slope in western Nepal, a region of relatively light summer rain. The next strongest common signal is in *Abies spectabilis* at Gonga Danda (GON), a high elevation site in east-central Nepal, and at lower elevation in chir pine (*Pinus roxburghii*) at Tila Nala (TLN). Both these chronologies have intermediate mean sensitivity, standard deviation, and autocorrelation. The weakest common signal and strongest autocorrelation were for *A. spectabilis* at the second highest elevation site for which a chronology was developed, Gurchi Lekh (GLH) in western Nepal. The highest elevation site for which a chronology was developed, Kalingchok (KAC), has the second weakest common signal and second highest first-order autocorrelation.

Correlations between the ten chronologies are in general weak (Table 4), but the strongest are within two contrasting groups of chronologies. The first is between lower elevation chir pine (*Pinus roxburghii*) at Tila Nala (TLN) and midelevation *Pinus wallichiana* at Rara National Park (RAP), both in western Nepal. The other group consists of chronologies of *Abies spectabilis*, the highest correlation being between high-elevation north or northwest facing series, one in central Nepal, Ghorepani (GHO), the other, Gonga Danda (GON), about 200 km distant in eastern Nepal. The two highest elevation *Abies* chronologies (KAC and GLH) are the next most strongly correlated.

DISCUSSION AND CONCLUSIONS

This small sample of material from Nepal has yielded some encouraging results that should be followed up by more intensive subregional sampling. One chronology of *Cedrus deodara* with excellent internal dating and hence strong common signal has resulted, suggesting that this species should be studied further. The one chronology each of *Pinus roxburghii* and *P. wallichiana* developed indicate moderate promise for these species. Ring-width chronologies of high elevation *Abies spectabilis* may also have some utility, although published work on its congener *A. pindrow* indicates that densitometric data may be much more useful in this case (Hughes 1992; Hughes and Davies 1987).

The general weakness of correlations between the ten chronologies is not entirely surprising, given the large distances between many pairs of sites (up to 600 km), the high relief of the terrain, and the variety of species and ecological conditions represented. In addition, it is likely that there was a wide range of ecological conditions and site histories, which would in turn serve to mask common climatic influences. In spite of the weakness of these correlations, we believe that a systematic sampling program would be worthwhile. This might focus on ring-widths from *C. deodara, P. roxburghii,* and *P. wallichiana* in western Nepal and other rain-shadow regions as potential records of past moisture conditions and on wood densities from subalpine *A. spectabilis* as records of spring and summer temperatures. In all cases, careful selection of sites, species, and individuals would be important, not only to identify those most likely to yield a clear and strong climate signal, but also to avoid cases where that signal has been disrupted by human or natural disturbance.

The major obstacle to the successful use of such a network is the paucity of instrumental meteorological data in Nepal that might be used in the derivation of transfer functions. It is likely that this obstacle will only be overcome if very strong regional patterns of interannual variability emerge for some tree-ring variable that could be linked to climate fluctuation in a larger region where more meteorological stations are available. Experience in other regions suggests that maximum latewood density of alpine conifers is the tree-ring variable most likely to show such regional cohesion (Briffa et al. 1988, 1992; Hughes 1992; Hughes and Davies 1987; Hughes et al. 1984; Schweingruber 1987).

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