

## A DENDROCHRONOLOGICAL STUDY OF *CRYPTOMERIA JAPONICA* IN JAPAN

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### ABSTRACT

Living specimens of *Cryptomeria japonica* D. Don var. *radicans* Nakai collected in western Japan were analyzed to evaluate the research potential of this tree species for future development of dendrochronology and dendroclimatology in Japan. A sufficiently strong correlation of tree growth with climatic factors was obtained in the residual chronology in which the variance due to autocorrelation was removed. It was also revealed that regional average climatic data are strongly correlated with tree growth. Thus, *Cryptomeria japonica* appears to have a promising potential for chronology-building and climatic reconstruction in Japan.

Die kürzlich im Westen von Japan gesammelten lebenden Baumproben von *Cryptomeria japonica* D. Don var. *radicans* Nakai wurden auf ihre Brauchbarkeit für weitere Studien für die Dendrochronologie und Dendroklimatologie in Japan untersucht. Eine genügend starke Korrelation zwischen Baumwuchs und klimatischen Faktoren wurde ersichtlich in der verbliebenen Chronologie, in welcher Abweichungen wegen Autokorrelation nicht berücksichtigt wurden. Es zeigte sich auch, dass die durchschnittlichen regionalen Klimadaten stark mit dem Baumwachstum übereinstimmen. So also verspricht *Cryptomeria japonica* eine geeignete Holzart für das Studium der Jahrringschronologie und Klimabestimmung früher Jahre in Japan zu sein.

Des spécimens vivante de *Cryptomeria japonica* D. DON var. *radicans* NAKAI échantillonnés dans le Japon occidental, ont été analysés pour évaluer le potentiel de recherche que constitue cet arbre, pour un développement futur de la dendrochronologie et de la dendroclimatologie au Japon. Une corrélation suffisamment forte entre la croissance et les facteurs climatiques a été obtenue dans la chronologie résiduelle après extraction de la variance due à l'autocorrélation. Il est également apparu que les données climatiques régionales moyennes sont fortement corrélées avec la croissance de l'arbre. En conséquence, *Cryptomeria japonica* apparaît comme un matériel potentiel de valeur pour la construction de chronologie et pour effectuer des extrapolations climatiques au Japon.

日本における杉による年輪編年の確立と気候復元の可能性を探るため、西日本において採集された現生芦生杉サンプルについて年輪幅と気候との相関が調べられた。分析の結果、前年成長との自己相関を除去した残差時系列に基づく指標編年において気候因子との充分且つ最も高い相関が認められた。又、複数地点で得られたデータを平均化した地域気候データとも高い相関の認められる事がわかった。これらにより、桧、高野檜と並んで杉もまた日本における年輪編年の確立と気候復元にきわめて有望な樹種である事が明らかとなった。

### INTRODUCTION

Along with other countries in the Far East, Japan has, until recently, long been one of the last frontiers in dendrochronological research in the world. Attempts to explore the feasibility of dendroclimatology in Japan have intermittently been made by some domestic scholars since the beginning of this century. Yet, no regional master

chronology correlating several different specimens collected from one or more sites has been produced. Much less have any research paradigms upon which cumulative studies could be developed been formulated until recently.

However, the last couple of years have witnessed a remarkable breakthrough in the state-of-the-art of Japanese dendrochronological studies. Since the early 1980's, scholars have initiated long-term research programs to delve into the viability of dendrochronology and dendroclimatology in this country. Aided by up-to-date research equipment, these projects have achieved remarkable success in disclosing promising potential of certain tree species for chronology-building and, possibly, climatic reconstruction.

With these pioneering undertakings, the door to a paradigmatic stage of the research tradition in Japanese dendrochronology and climatology has been opened. Nevertheless, much work needs to be done to consolidate theoretical and methodological underpinnings of prospective research developments in this temperate humid habitat. The present study examines the potential of *Cryptomeria japonica* D. Don, Japanese cedar, for future chronology-building and climatic reconstruction in this country.

### BRIEF REVIEW OF JAPANESE TREE-RING STUDIES

Japanese tree-ring studies consist of two mutually dissociated research traditions: chronology-oriented and climatology-oriented. The scholars in the former tradition are concerned with tree-ring dating, as well as climatic reconstruction, while the latter scholars are interested exclusively in correlating tree-growth with climatic or other variances. Climatology-oriented scholars began the Japanese tree-ring analysis in the early 1900's, whereas, the chronology-oriented research tradition took shape as late as the current decade. What is crucial is that virtually no interest in tree-ring dating is present among climatology-oriented researchers, which hampers beneficial information exchange between these two research traditions.

The earliest tree-ring studies in Japan can be traced back to the 1920's to 1930's by scholars with the interest in past climatic variability (Yamazawa 1929, Shida 1935, Enmoto 1937). These scholars isolated low frequency cyclical variance with varying periodicity observable in a long tree-ring series (300 to 1000 years) of living trees (*Castanea crenata* Sieb. et Zucc., Formosan cypress and *Cryptomeria japonica*) collected from Japan and Formosa. Yamazawa and Shida further tried to correlate the periodical growth variations with historically documented climatic and other anomalies. These early scholars were more interested in long-term cyclical variance of tree growth rather than variance in annual growth.

Concerns with variance at frequencies lower than yearly variation and their casual nexus are recurrent and characteristic features in climatology-oriented studies from the inception of this research tradition to the present. Yamamoto (1949) argued that the growth curve of *Chamaecyparis obtusa* (Sieb. et Zucc.) Endl. collected from central Japan, which was created with an 11-year moving average, fits well with the fluctuation of local summer precipitation, which he claimed to be correlated eventually with the perturbation of sunspot activity. Saito (1950) also utilized a decade ring width averages calculated in five-year intervals for *Picea jezoensis* (Sieb. et Zucc.) Carriere and *Kalopanax pictus* (Thunb.) Nakai collected from northern Japan in his pilot study on climatic influence upon tree growth. Outi (1964) examined the correlation of ring width variance of varying periodicities (5, 10, 20 and 100 years) recognized on *Zelkova*

*serrata* (Thunb.) Makino from northern Japan with various climatic and other factors. The 11-year periodicity of growth recognized for Formosan cypress by Outi in the 1960's was recently reconfirmed to be correlated with sunspot cycles by Mori (1981) through applying sophisticated time-series analysis. Takata (1980) examined the percentage variance reduced by climate for *Cryptomeria japonica* from central Japan using radial measurements of five-year intervals, rather than consecutive years. His study is, however, based upon a simple assumption that the common variance shared among different trees is caused by climatic variances. Noda *et al* (1983:23) mentioned that Takeichi recently studied the correlation between radial growth of *Cryptomeria japonica*, *Chamaecyparis obtusa* and *Pinus densiflora* Sieb. et Zucc. from western Japan with local temperature and precipitation. One of his conclusions is that only 40 percent of total variance in *Pinus densiflora* is reduced by climatic factors. Whether Takeichi adopted annual growth in consecutive years or combined ring widths in certain intervals is not mentioned.

Thus, the majority of known studies in the climatology-oriented research tradition have focused, not on annual ring growth, but on lower frequency variance. For this reason, most of the findings obtained in this research tradition are, unfortunately, not directly relevant to chronology-oriented studies.

As already noted, the beginning of chronology-oriented research appears in the current decade. However, a few scholars conducted feasibility studies of dendrochronology in Japan between the 1950's and 1970's, but none could create a regional master chronology (Sahara 1983). Since no report on these early attempts has thus far been published, technical details of the undertakings remain unknown. Before 1980, the only known published account on the viability of dendrochronology in Japan with the citation of empirical evidences is possibly that of Arakawa (1960). Arakawa expressed a pessimistic view on the feasibility of dendrochronology in Japan based on the low correlation observed between tree-ring series of *Chamaecyparis obtusa* in central Japan and of Formosan cypress in Formosa originally measured by Yamazawa and Shida in the early 1900's.

In the beginning of the 1980's, scholars affiliated with the Nara National Cultural Property Research Institute in Nara started a research program explicitly to establish dendrochronology in Japan. Living specimens of *Cryptomeria japonica*, *Chamaecyparis obtusa* and *Sciadopitys verticillata* (Thunb.) Sieb. et Zucc. from central and western Japan were analyzed in initial feasibility studies (Mitsutani 1981, 1982). With the promising results obtained in these pilot studies, programs were also begun to make floating chronologies starting around the 8th century A.D., as well as living chronologies for *Chamaecyparis obtusa* and *Sciadopitys verticillata* (Mitsutani 1984). For floating chronologies, mainly posts excavated from the ancient palace site were utilized. In November of 1985, the gap between the living and the floating chronologies of *Chamaecyparis obtusa* was bridged to form a 2000-year chronology from 38 BC to the present (Anonymous 1985). With the *Chamaecyparis* chronology, the dating of some historic and prehistoric remains has already been accomplished. It is noted that the correlation of ring series more distant than 200 km is possible for the chronology of this species (Mitsutani 1984:7).

Scholars in the Kyoto University Research Reactor Institute in Kyoto have also initiated a research project to explore the feasibility of dendrochronology in Japan concurrent with Nara's research. Fairly good correlations between living specimens of *Chamaecyparis obtusa* within and between sites *ca.* 20 km apart in western Japan have

been reported (Noda *et al* 1983). Also, response functions were provided for *Chamaecyparis obtusa* and *Cryptomeria japonica* obtained from the same and other sites (Noda and Higashimura 1985).

In addition to these two institutions, researchers in the Tokyo National Cultural Property Research Institute in Tokyo have also started research in collaboration with their Nara counterparts. A good potential for chronology-building is suggested for *Chamaecyparis obtusa* collected in central Japan based on the reexamination of the 800 year ring-width series by Yamazawa in the 1920's (Ito and Miura 1982).

For non-destructive tree-ring observations, a study of the application of computed tomology (CT) is currently under way (Onoe 1986).

In a different vein from the above two research traditions, the effect of air pollutants on growth of *Pinus densiflora* collected in central Japan was recently examined by Yokobori and Ohta (1983). Past temperature fluctuation from A.D. 160 to 1900 was also extrapolated through stable isotope ratios on a long-lived specimen of *Cryptomeria japonica* collected from southern Japan (Libby 1983:30, 40-42).

## DENDROCHRONOLOGY AND DENDROCLIMATOLOGY OF *CRYPTOMERIA JAPONICA*

As reviewed in the preceding section, the current dendrochronological studies in Japan are concerned mainly with three tree species: *Chamaecyparis obtusa*, *Sciadopitys verticillata* and *Cryptomeria japonica*. A major reason for this concern is that these species are the most commonly utilized trees for wood crafts and constructional purposes in both historic and prehistoric times (Shimakura 1975: 290-292). However, while chronology-building is presently under way for the first two species in the Nara Research Institute, *Cryptomeria japonica* is not included in this project. Nor has the eligibility of this particular species for chronology-building been thus far fully revealed, although good potential is suggested by some studies, as noted above. In the following sections, the feasibility of dendrochronology and dendroclimatology of *Cryptomeria japonica* is explored through the analysis of living specimens.

The *Cryptomeria japonica* which is endemic to the Japan Sea side of the country is distinguished to be *Cryptomeria japonica* D.Don var. *radicans* Nakai from var. *japonica* on the basis of its characteristic way of reproduction through layering of lower branches (Japan Forest Technical Association 1964: 42). The sample specimens utilized for the present analysis belong to the *radicans* variety.

## SAMPLES

One of the major obstacles in Japanese dendrochronological and climatological studies lies in sampling living specimens in natural forests. Regardless of tree species and whether samples are collected in the form of discs or increment cores, it is difficult to collect appreciable numbers of recent specimens from intact forests in present day Japan. Natural or semi-natural forests that have not been subjected to intensive man-induced disturbances have rarely survived throughout the archipelago. A few such forests are strictly protected from further impairment by governmental, religious or other agencies. The present samples were all collected in the Ashiu Experimental Forest of Kyoto University, located in the inland montane region of western Japan (Figure 1).

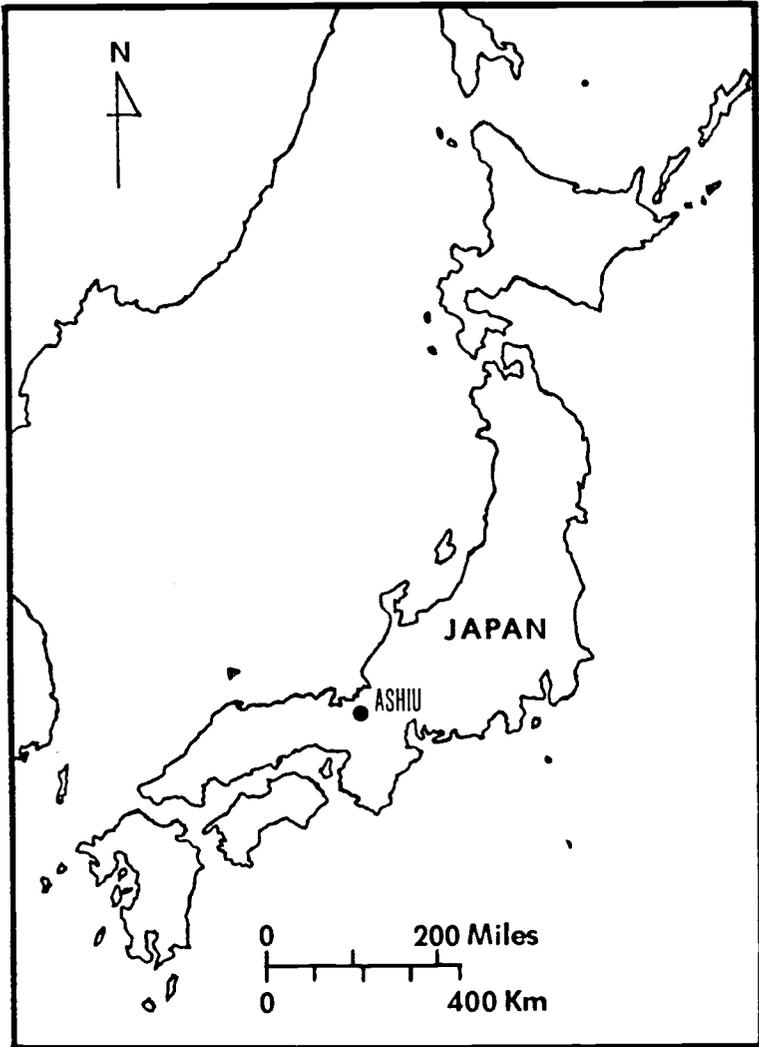
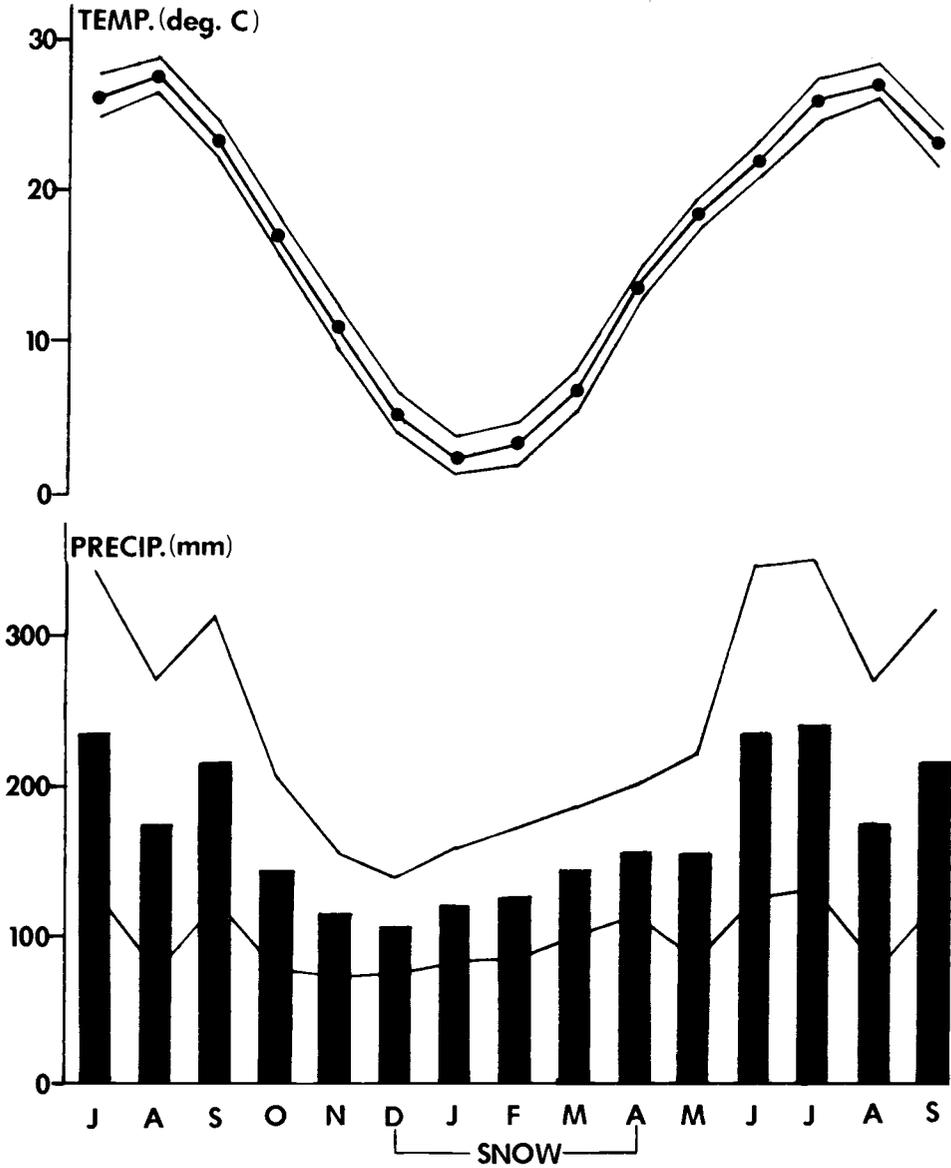


Figure 1. Location of Ashiu.

The elevation of the forest ranges from 400-960 m above sea level. Most portions of the forest consist primarily of *Cryptomeria japonica*, but *Cryptomeria* occurs in some parts with broadleaf trees such as *Fagus*, *Quercus*, *Aesculus*, and *Acer*. The annual precipitation of the area is approximately 2500-3000 mm with a summer rainy season (June through September) and a winter snow season (December through April). The annual mean temperature is around 13° C with the highest usually recorded in August and the lowest in January (Figure 2).

The samples were collected from three separate localities (ca. 1 to 3.5 km apart) within the forest. All three localities are in the middle rather than along the margin of the forest. Core samples were taken at about breast height or higher with a 4.3 mm



**Figure 2.** Monthly mean temperature and total monthly precipitation in Ashiu. Mean and standard deviation from 1925 to 1980.

**Table 1.** Sampling localities and samples.

	Locality 1	Locality 2	Locality 3
Total number of tree	10	5	13
Total number of radius	20	20	45
Sampling date	December 1983	December 1983	June 1985
Locality name	Yonrinpan	Sanrinpan	Jurinpan
Latitude	35°20'16"N	35°20'49"N	35°19'3"N
Longitude	135°44'5"E	135°43'53"E	135°44'50"E
Altitude	ca. 760m	ca. 650-700m	ca. 840m
Slope direction	Southwestward	Unknown	Southward to Southeastward
Dip	ca. 10°	Unknown	ca. 30°-45°

increment borer of 40 cm length at localities 1 and 3. Disc samples were provided by the forest office to the author from stockpiled logs, which were cut at locality 2. Sampling localities 1 and 3 were selected because of the abundance of *Cryptomeria japonica* and easy access. A total of 65 cores and five discs from 28 trees were collected in 1983 and 1985 from these three localities (Table 1).

In the initial sampling in 1983 at locality 1, increment cores were taken from two opposite radii for each tree. However, since inter-radius variations of ring width was sometimes unexpectedly large during later laboratory inspections, three or more cores were taken from individual trees in locality 3 during the second sampling in 1985.

At locality 1, every adjacent tree irrespective of its trunk size was sampled, while at locality 3, the larger specimens were selectively sampled because most samples collected during the first sampling at locality 1 proved to be less than 100 years old. The large difference in the length of tree-ring series between localities 1 and 3 is a result of this change in sampling strategies.

The lower portion of almost all of *Cryptomeria japonica* in this particular forest is damaged by habitual bark peeling and chewing by wild bears that inhabit the forest. This bark peeling causes severely distorted rings in peeled and surrounding portions of all trees. Although attempts were made to avoid this distortion as much as possible while taking increment cores and demarcating radii for measuring discs, it was often difficult to avoid completely the effect of this disturbance.

### CHRONOLOGY DEVELOPMENT

All the samples collected were processed in the Laboratory of Tree-Ring Research of the University of Arizona. After absent and false rings were determined through manually drawn skeleton plots (Stokes and Smiley 1968), samples were measured using the Bannister tree-ring measuring machine. Measurement errors were checked through the check measurement program in the Laboratory. Upon inspecting rough growth patterns with graphical plots of the decade means of raw measurements, all series were compared with each other as a group, and various statistics were computed for each series with computer program COFECHA (Holmes 1983). Absent and false rings, as well as measurement errors, were double-checked by inspecting the correlation coefficients obtained by comparison of each series with the master chronology in each locality computed for partially overlapping fifty year intervals.

**Table 2.** Statistics relevant to chronologies. (1) = Range of chronology, (2) = Common interval analysis, (3) = Number of tree and radius used for (2), (4) = Within tree mean correlation, (5) = Between tree mean correlation, (6) = All radii mean correlation, (7) = Mean sensitivity, (8) = Standard deviation, (9) = First-order autocorrelation for all periods, (10) = Second-order partial autocorrelation for all periods, (11) = First-order autocorrelation before AD1850, (12) = First-order autocorrelation after AD1850.

	Locality 1			Locality 2			Locality 3			All Localities		
	Standard	Residual	ARSTAN	Standard	Residual	ARSTAN	Standard	Residual	ARSTAN	Standard	Residual	ARSTAN
( 1 )	AD1847-1983			AD1767-1983			AD1750-1985			AD1767-1985		
( 2 )	AD1932-1981			AD1849-1983			AD1923-1985			AD1927-1981		
( 3 )	9 trees 15 radii			5 trees 18 radii			13 trees 40 radii			27 trees 73 radii		
( 4 )	0.496			0.595			0.586			0.565		
( 5 )	0.338			0.323			0.329			0.278		
( 6 )	0.349			0.371			0.348			0.289		
( 7 )	0.1828	0.2264	0.1811	0.1647	0.2030	0.1575	0.1583	0.1925	0.1633	0.1260	0.1611	0.1185
( 8 )	0.3142	0.2120	0.2464	0.2714	0.1785	0.2864	0.2278	0.1909	0.2331	0.1852	0.1410	0.1925
( 9 )	0.7089	-0.1068	0.5152	0.7058	-0.0776	0.7547	0.5255	-0.0666	0.5746	0.5959	-0.0822	0.6579
(10)	0.1975	-0.1048	0.0832	0.2497	0.1123	0.2928	0.0792	-0.0598	0.0455	0.1771	0.0367	0.1186
(11)						0.3260						0.4450
(12)			0.5152			0.7584						0.6880

After completing the series of data quality control, raw measurement series in each locality were standardized and combined to create chronologies for the respective localities with computer program ARSTAN (Cook 1985, Cook and Holmes 1985). Double-detrending with negative exponential curves and stiff cubic spline were employed for standardization of each ring width series.

The program ARSTAN is devised for optimal and objective standardization of tree-ring series collected from mesic and closed canopy forests. In comparison with the trees in arid or semi-arid sites in which trees are widely spaced, trees in closed canopy forests are more susceptible to localized disturbances, such as death of nearby aged trees, opening of canopy by windblow, etc. This is due to narrower spacing between trees, and therefore, more competitive interactions. Since the effect of these disturbance pulses on ring width series normally lasts a number of years, i.e. it is autocorrelated, it can be minimized through autoregressive modeling. In order to retain climatically induced autocorrelations, however, the persistence common to the ensemble of tree-ring series which is likely to be caused by low-frequency climatic variances needs to be reintroduced into a residual time series.

The program ARSTAN generates three discrete chronologies: standard, residual and ARSTAN. In the standard chronology, the series without prior autoregressive modeling are combined to create a composite chronology. In the residual chronology, the variance due to autocorrelation is removed from each series through autoregressive modeling. In the ARSTAN chronology, the pooled autoregression is added to the residual chronology. When combining each series to create a composite chronology, biweight robust mean is utilized.

After generating three chronologies in each locality, ring series were combined to create a master chronology for the entire site. Because of the upper limit in the number of tree-ring series the ARSTAN program can accommodate (*i.e.* 80), some short series were omitted before making composite chronology.

When building chronologies for each locality and for the composite chronology for all localities, the time periods (23 to 101 years) of ten series bearing low correlations (below 0.2) with the master chronology were omitted.

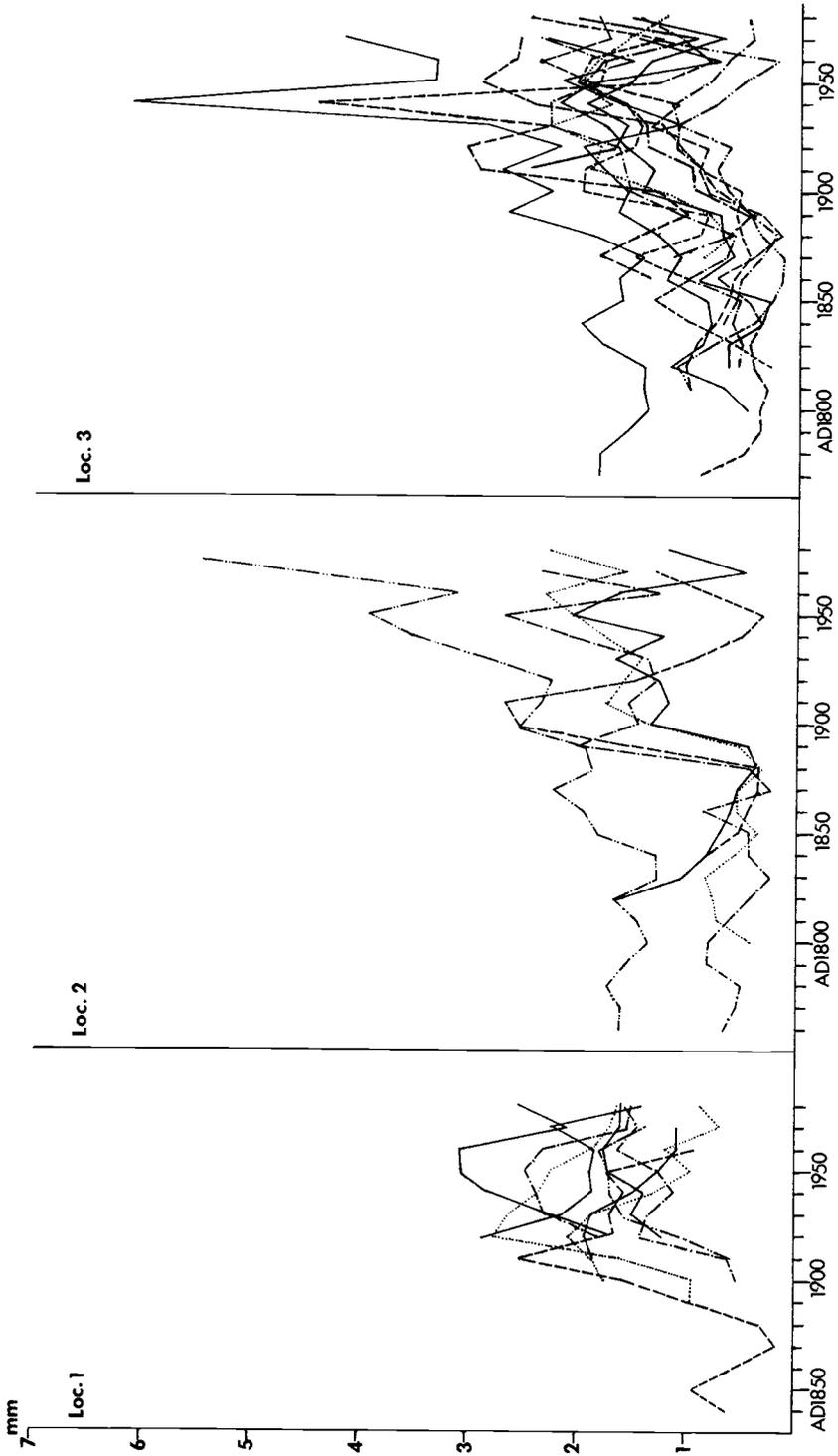
## GENERAL CHARACTERISTICS OF CHRONOLOGIES

Statistics for the chronologies for each locality and for the residual master chronology are presented in Table 2. All the raw measurement and index data for each chronology are available from the International Tree-Ring Data Bank, the Laboratory of Tree-Ring Research, the University of Arizona.

Visually, the repetition of highly contrasting wide and narrow ring periods within a single series is a salient characteristic of the samples. Plots of the decade means of individual trees represent this characteristic (Figure 3).

False rings sometimes appeared only in the late wood portion of very wide rings, while absent rings occurred only in the periods of extremely narrow rings.

A conspicuous rise in growth is visible for most trees during the period of A.D. 1870 to 1900. Exactly the same punctuated rise of annual growth around 1907 is reported at a site *ca.* 2.5 km southwest of locality 3 within the same forest (Shidei *et al* 1958:23-25). Shidei *et al* (1958:24) also mention that the official records on past forestry activities document intensive deforestation between 1893 and 1915, during which time large numbers of *Castanea crenata* and smaller numbers of *Cryptomeria japonica* and *Chamaecyparis obtusa* were cut mainly for railroad tie manufacture.



**Figure 3.** Decade means of ring measurements. Each line represents a tree-ring series of each tree.

There is a slight lag between the episodes discerned in the present localities and in the locality reported by Shidei and others, as well as the documented intensive deforestations. This time difference may reflect the fact that the progression of deforestation from one site to another occurred over several years. Thus, it is likely that the abrupt rise of annual growth during 1870 to 1900 in the present samples is a consequence of removing competitive trees in the same stand due to intensive deforestations. The fact that the year in which growth anomalies begin is not exactly the same for different trees, even in the same locality, and that the number of old trees (older than 100 years) is small, at least in localities 1 and 3, bears out this possibility. Albeit relevant records on past forestry activities are not available, some or most of the accelerated growth with smaller amplitude present in other periods could also result from the clearance of a tree's immediate environ. Overall, deforestation in this forest, at least during the recent past, seem to be much more intensive than originally expected. Due to this frequent human disturbance, it is difficult to isolate intrinsic age trends of the specimens.

Mean of correlation coefficients between series within the same tree ranges from 0.5 (Loc. 1) to 0.6 (Loc. 2). However, whether these values can be applied to *Cryptomeria japonica* in general cannot be determined, because of the adverse effects of bark peeling upon concentricity of annual rings possibly affecting the values.

Mean sensitivity of the three chronologies in each locality is relatively low, about 0.2, which is consistent with visual impressions of complacent ring patterns. In the three localities, residual chronologies always produce the highest value of mean sensitivity.

The first-order autocorrelation (0.5 to 0.8) is high in both the standard and ARSTAN chronologies in each locality, while second- and third-order partial autocorrelations are generally negligible. With a closer look at the first-order autocorrelation computed for 50-year intervals, the values of the coefficients drastically increase after 1850. This rise of autocorrelation is a consequence of the sudden acceleration of tree growth after 1870. Thus, the high values of first-order autocorrelation do not represent those in an undisturbed forest. The lowest coefficient value observable before 1850 (0.3) is probably closer to the intrinsic first-order autocorrelation of *Cryptomeria japonica* in natural forests.

Standard deviations of the three chronologies in each locality range from 0.2 to 0.3. The smallest standard deviation consistently belongs to the residual chronology in each locality because persistence has been removed.

Since most of the sudden accelerations of tree growth observed among samples were caused by removal of competitive trees, a major proportion of autocorrelation discerned in standard chronologies is unrelated to climatic fluctuations. As the deforestations occurred almost contemporaneously in each locality, adding common persistence to the residual chronology obscures potential climatic signals inherent in tree-ring variations. Under such a circumstance, the removal of autocorrelation is the best way to extract climatically induced variances. The above findings regarding the interrelationships between standard, residual and ARSTAN chronologies in each locality are quite understandable in this context. It should be noted that the ARSTAN chronology is designed to cope with localized or tree-specific disturbances among a set of tree-ring samples. It is not effective when a sampling site was deforested so extensively that every tree was nearly synchronously affected and competitive suppressions were greatly reduced by those deforestations.

There is little difference in inter-tree correlations between trees in each locality and trees in all localities combined together. However, graphical plots of growth indices for the residual chronology do not necessarily coincide perfectly between different localities (Figure 4). Nonetheless, it is possible to specify some diagnostic years in which tree growth is conspicuously diminished across all three localities (*e.g.* 1970, 1966, 1904, 1881, 1871, 1868, *etc.*).

The time period from 1885 to 1895 exhibits somewhat anomalous oscillations in chronologies for locality 2 and 3 and, as a result, in the composite master chronology for the entire site. These anomalies are an outcome of the severe distortion and reduction of climatically generated variances in this particular period during which the most intensive deforestations would have occurred in the sampling localities.

### RESPONSE FUNCTION

Response functions were computed for the three chronologies in each locality and for the master residual chronology for the entire site utilizing the computer program RESPO (Lough 1984). RESPO converts input variables (climatic variables and prior growth) into eigenvectors and executes multiple regression of the amplitudes of eigenvectors in order to avoid the effect of the multicollinearity involved in the predictor variables.

For the chronologies in each locality, climatic data recorded at the office of Ashiu Experimental Forest ( $35^{\circ}18'N$ ,  $135^{\circ}43'E$ , Elev. 359 m) were utilized. The observation site is located about three to five km from and about 300 to 500 m lower than the three sampling localities. For the master residual chronology of the entire site, two climatic data sets were utilized in computing response functions: (1) the same climatic data of Ashiu as used for response functions of chronologies in each locality, (2) the averaged regional climatic data of Ashiu and two additional stations, *i.e.* Kyoto University Honbu Shikenchi ( $35^{\circ}02'N$ ,  $135^{\circ}47'E$ , Elev. 60 m) and Kamigamo Shikenchi ( $35^{\circ}45'E$ , Elev. 140 m) which are situated 29 to 35 km south and 780 to 510 m lower than the sampling localities, respectively.

The time period of climatic records utilized is from 1925 to 1980 (56 years). Missing values in the climatic data were interpolated by averaging values of the month of the years for which observations are present. Thirty climatic variables, monthly mean temperature and total monthly precipitation for 15 months from July of the preceding year to September of the growth year, and three years of prior growth were employed as potential predictor variables except for residual chronologies for which only climatic variables without prior growth were utilized.

In the multiple regression, principal component regressors were selected with *T*-values of the predictor variables entering regression being greater than or equal to one. Ninety-five percent confidence limits of the regression coefficients were utilized to select significant predictor variables.

Response functions obtained for corresponding chronologies between each locality are not identical, yet are similar to each other regarding the percentage variance reduced by climate and selected significant predictor variables (Table 3 and 4). However, there is a relatively large discrepancy in the variance explained by prior growth between standard chronologies of locality 1 (40%) and of localities 2 (3%) and 3 (5%), while the variance reduced by climate is similar. This inter-locality difference in the variance reduced by prior growth is certainly because the chronology in locality 1 falls on the time period in which deforestations are severe, while those in localities 2

and 3 include the period before the severe disturbances started. It is a reasonable outcome that the variance reduced by prior growth is consistently high (37 to 54%) and the difference between localities is much smaller in the ARSTAN chronology in which common persistence is added.

The percentage variance reduced by climate is 43 to 62 percent for standard, 65 to 70 percent for residual, and 32 to 46 percent for ARSTAN chronologies. Residual chronologies in which mean sensitivity is always the highest in each locality appear to be the most sensitive to yearly climatic fluctuations in all three localities.

Since the residual chronologies contain the largest amount of climatic signal in each locality, response functions were computed only for the residual master chronology for the entire site. The percentage variance reduced by climate indicates no significant difference between the use of climatic data of Ashiu and regional average climatic data. Nevertheless, the number of significant predictor variables greatly increases in the latter from seven to twelve, because of the decreased margins of 95 percent confidence limits associated with most predictor variables. This is a result of the decrease in the number of regressors entered into the multiple regression, i.e. the increase in the degree of freedom. Thus, the overall reliability of the response functions is enhanced when adopting macroclimatic data.

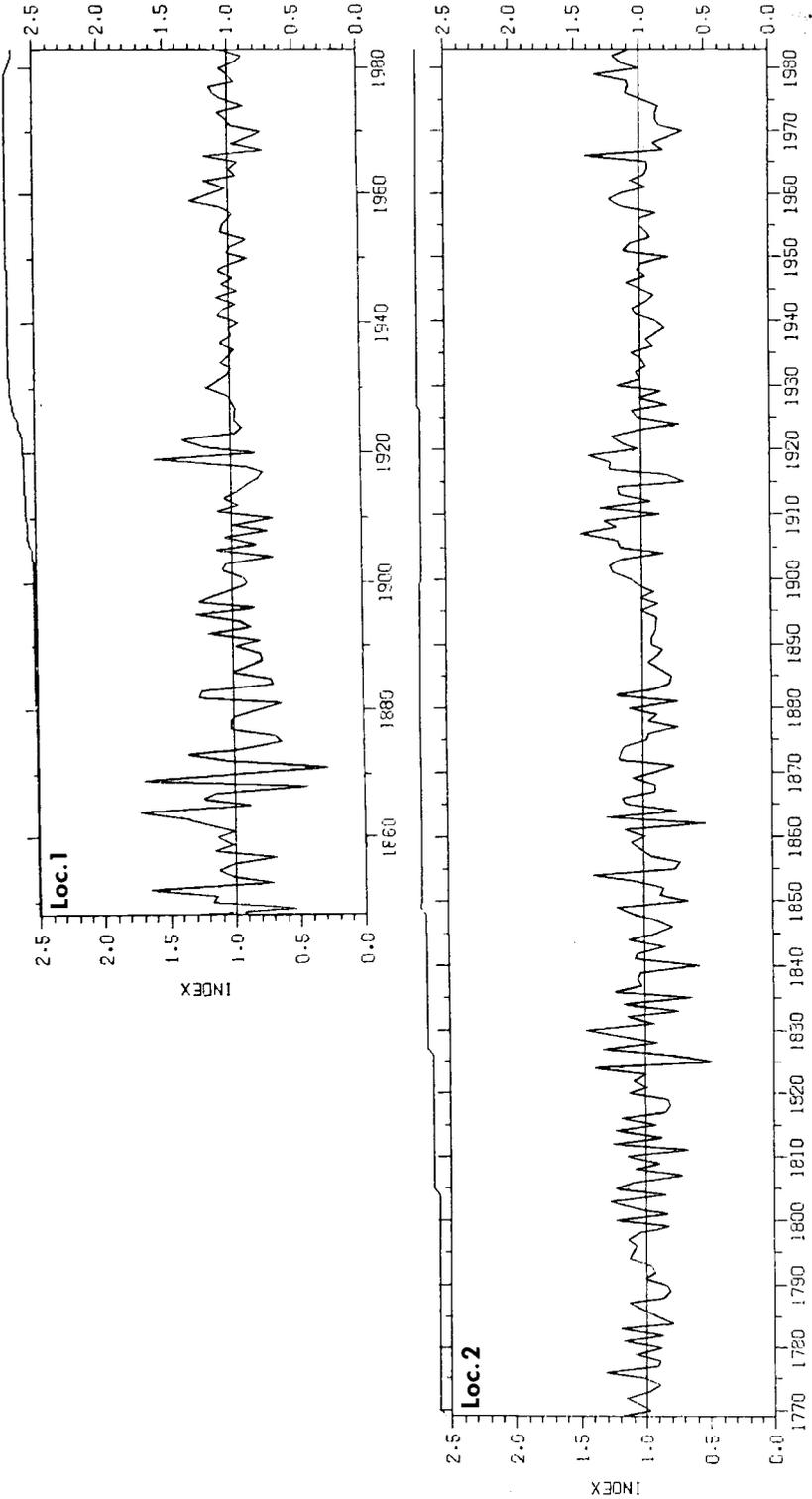
The response function for the residual master chronology computed with regionally averaged data is presented in Figure 5. Cambial growth possibly commences from the current May in which a large correlation of temperature with the growth is discernible. The negative effect of temperature in this month indicates soil moisture to be a limiting factor. In the following month, the current June, however, the correlation of temperature becomes positive as a result of the beginning of a rainy season in which a drastic increase of precipitation occurs. In the current July, the effect of temperature on cambial growth again reverses. This is possibly because the evaporation of soil moisture due to the continual rise of temperature counteracts a slight increase of precipitation in this month. After the end of the rainy season, in the current August, a rapid decline of precipitation with a slight increase of temperature makes rainfall a positive controlling factor. By the end of this month, most of cambial growth probably ceases, because there are no significant correlations of either temperature or precipitation in the current September.

During the snow season in which the amounts of net photosynthesis diminish, smaller correlations of climatic factors with cambial growths observable are a reasonable outcome. During the season in which soil moisture is sufficiently large, higher temperature associated with less cloud cover, i.e. less snowfall, is positively related to the amount of net photosynthesis.

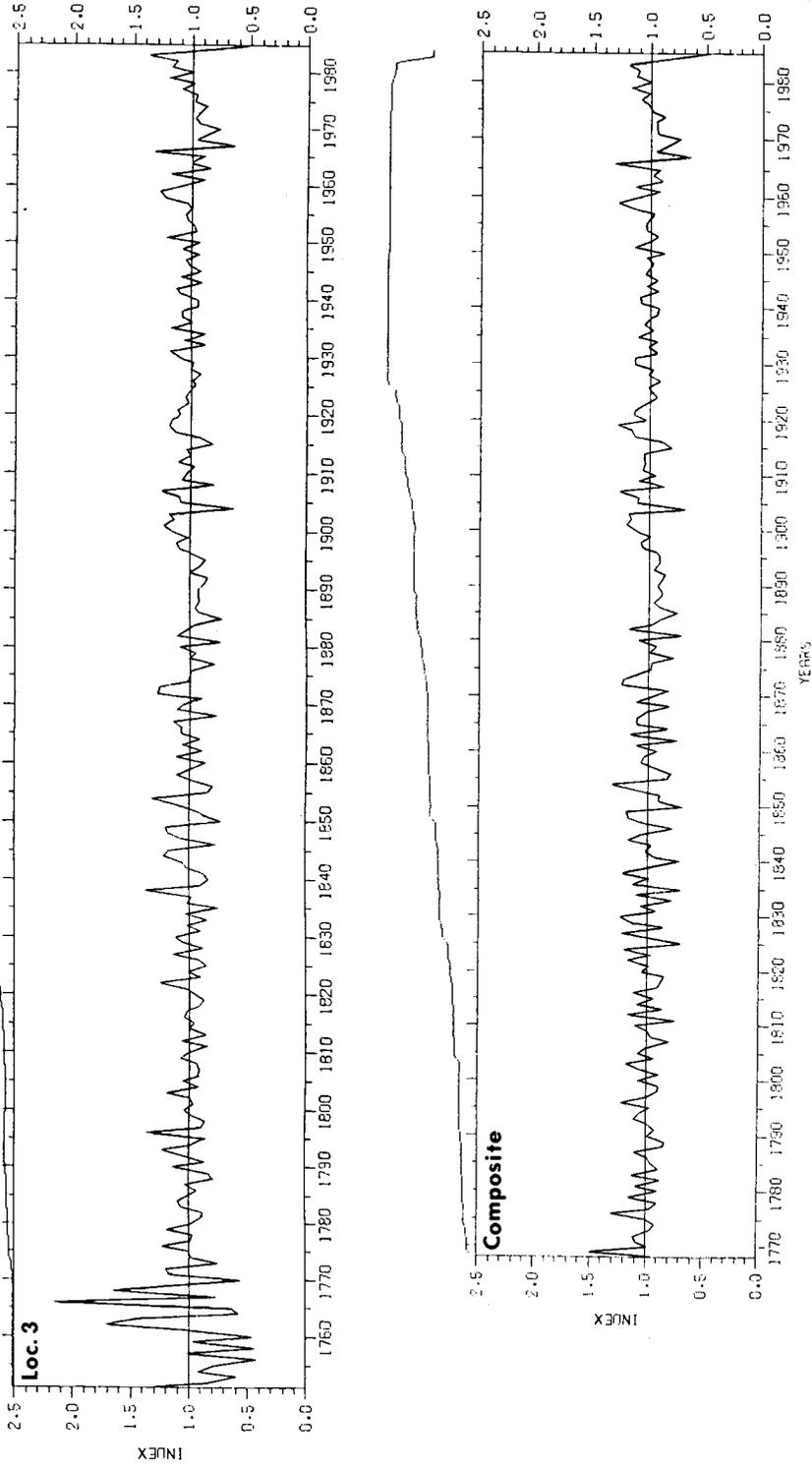
In summer and autumn of the prior year, soil moisture limited by precipitation is generally a strong determinant. However, in the prior July, solar radiation also positively regulates the amount of net photosynthesis.

Overall, water stress during the current spring and summer, and the prior summer and autumn is a major limiting factor to radial growth. The water stress is largely controlled by the balance between precipitation and evaporation due to high temperature.

As already noted, response functions for the *Cryptomeria japonica*, as well as other species obtained from the two sites, located approximately 90 and 120 km south to the present sampling localities, have been briefly summarized by Noda and Higashimura (1985:13-14). They provided plots of regression coefficients for monthly mean



**Figure 4.** Residual chronologies for each locality and for all localities. Line graphs above each chronology represent the number of tree-ring series represented in the index value for each year.



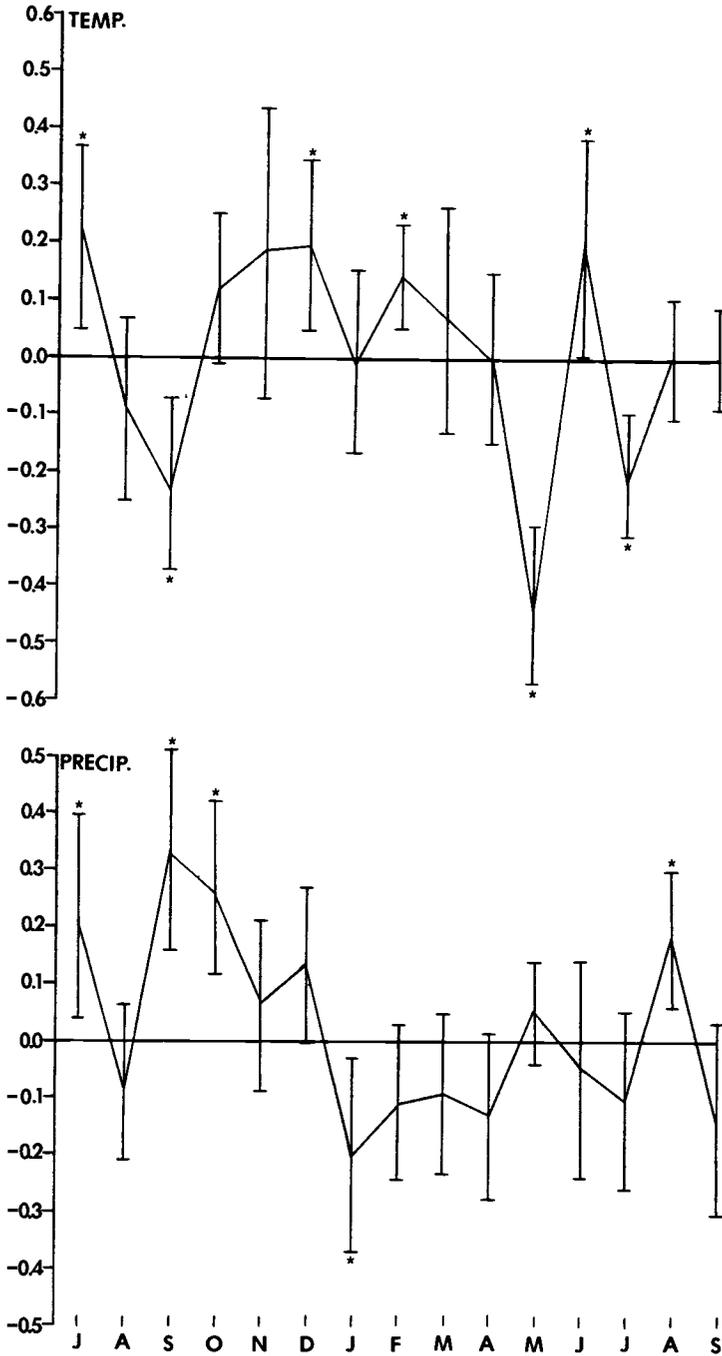
**Figure 4, continued**

**Table 3.** Statistics relevant to response function. (1) = Percentage variance reduced by climate, (2) = Percentage variance reduced by prior growth, (3) = Number of significant predictor variables, (4) = Residual chronology utilizing Ashiu temperature and precipitation, (5) Residual chronology utilizing regional average temperature and precipitation.

	Locality 1		Locality 2		Locality 3		All Localities	
	Standard	Residual	Standard	Residual	Standard	Residual	(4)	(5)
(1)	42.917%	70.1216%	56.847%	65.0463%	62.442%	65.7133%	38.834%	69.0212%
(2)	39.977%	37.127%	3.347%	53.734%	5.493%		44.484%	
(3)	12	8	14	9	13	9	8	12

**Table 4.** Significant predictor variables.

	Temperature			Precipitation												Prior Growth								
	Current			Current												Prior								
	S	A	J	S	A	J	S	A	J	M	A	M	F	J	D	N	O	S	A	J	-1	-2	-3	
Standard																								
Loc. 1	X		X	X		X	X		X				X		X	X	X	X	X	X	X	X	X	
Loc. 2		X	X	X		X	X		X	X	X		X	X	X	X	X	X	X	X	X			X
Loc. 3		X	X	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Residual																								
Loc. 1	X		X	X		X	X		X				X		X	X	X	X	X	X	X			
Loc. 2		X	X	X		X	X		X	X	X		X	X	X	X	X	X	X	X	X			
Loc. 3	X		X	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X			
ARSTAN																								
Loc. 1	X		X	X		X	X		X				X		X	X	X	X	X	X	X	X	X	
Loc. 2		X	X	X		X	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	
Loc. 3	X		X	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	



**Figure 5.** Response function for the residual master chronology utilizing regional average temperature and precipitation. Ordinate is standard index departure. Abscissa is months. \* Significant response.

temperature and total monthly precipitation from the prior January to the current September. However, most of the coefficients associated with climatic variables are different from the present findings. Given that detailed information regarding their analysis is currently not available, possible causes of such a discrepancy are unknown.

## SUMMARY AND CONCLUSIONS

The 85 tree-ring width measurement series obtained from 28 living specimens of *Cryptomeria japonica* D. Don var. *radicans* Nakai from a site in western Japan were analyzed to explore the research potential of this species for future chronology development and climatic reconstruction. Three chronologies: standard, residual and ARSTAN were created for each of three localities within the same forest and for the entire study area.

The viability of chronology-building was established, as sufficiently large variance (*c. a.* 70%) is reduced by climate and comparisons of chronologies between localities show significant correlations. Response functions revealed that water stress in the current spring and summer, and the prior summer and autumn, is a major determinant of radial growth. Because of the severe disturbances caused by human agent, the effect of prior growth on ring width in undisturbed situations could not be clearly isolated.

Of three different chronology options, the residual chronology has the highest correlation with critical climatic variables. The residual chronology, however, does not exploit potential climatic information possibly involved in autocorrelation. Nonetheless, this chronology would be the most eligible and requisite option for delineating climatic responses of the tree specimens obtained from sampling sites which have undergone intensive deforestations. In other words, by adapting residual chronology (or ARSTAN chronology in case of less severe disturbances), recent samples collected from such sites can even be utilized for the feasibility study of dendrochronology and dendroclimatology. This is a highly encouraging possibility for Japanese dendrochronological studies, since most of the forests available for tree-ring sampling in Japan have been subjected to severe deforestations during the last couple of centuries.

It was also revealed that the regionally averaged macroclimate is highly correlated with the residual master chronology. This is also a favorable finding with respect to the potential geographic coverage of a master chronology created from this species, as well as prospective research on regional climatic reconstructions.

In summary, *Cryptomeria japonica*, along with *Chamaecyparis obtusa* and *Sciadopitys verticillata*, is an eligible tree species bearing a fruitful potential for the future development of dendrochronology and dendroclimatology in Japan.

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