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A dendroclimatic analysis of *Pinus densiflora* from Mt. Chiri in southern Korea

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Abstract – The influence of climate on the radial growth of *Pinus densiflora* Sieb. and Zucc. in southern Korea was investigated using a 196-year (AD 1801–1996) tree-ring chronology developed from 27 trees sampled in the Chiri mountain range. The relationship between ring width and climate was analyzed using the response function, which indicated 56 % of the chronology variance attributable to climate. This analysis has demonstrated that warm January and March temperatures have a direct relationship to ring width. An inverse relationship has been noted with August precipitation. The association between tree growth and climate reveals the potential usefulness of this species in climatic reconstruction. (© Inra/Elsevier, Paris.)

***Pinus densiflora* / tree rings / growth–climate relationship / southern Korea**

Résumé – Une analyse dendroclimatique de *Pinus densiflora* au mont Chiri en Corée du Sud. L'influence du climat sur la croissance radiale de *Pinus densiflora* Sieb. et Zucc. en Corée du Sud a été étudiée en utilisant une chronologie de cernes de 196 ans (1801–1996 AD) développée à partir de 27 arbres échantillonnés au mont Chiri. La relation entre épaisseurs de cernes et climat a été analysée grâce à une fonction de réponse qui indique que 56 % de la variance de la chronologie est attribuable au climat. Cette analyse a démontré que des températures élevées en janvier et mars ont un effet positif sur la croissance. Un effet négatif a été noté pour les précipitations d'août. Cette association entre croissance et climat révèle les potentialités de cette espèce pour des reconstructions climatiques. (© Inra/Elsevier, Paris.)

***Pinus densiflora* / cernes d'arbre / relation croissance-climat / Corée du Sud**

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1. INTRODUCTION

The analysis of annual growth rings of trees growing on stressed sites provides coherent quantitative estimates of environmental variables [4, 5, 11]. Some species in Korea reported growing for several centuries [16] may provide unique opportunities for developing long tree-ring chronologies useful for climatic reconstructions from this region. Recent dendrochronological reconnaissances in southern Korea [25, 30] also indicated the possibility of finding multi-century old trees in some of the high mountain areas. Though this area is very important from a climatic perspective, only a few high-resolution tree-ring records are available for the Korean Peninsula [2]. Intensive chronology development efforts are currently underway to develop a high-quality representative geographic network of tree-ring chronologies for this region. The present report is the first dendroclimatic study on *Pinus densiflora* Sieb. and Zucc. from southern Korea.

P. densiflora is commonly referred to as Korean red pine or Japanese red pine. It occurs naturally in Korea, Japan and Manchuria, covering a wide ecological spectrum [22, 36]. It is a shade-intolerant species, favouring warm and moderate moist conditions during the growing season and dry conditions during the dormant season [21, 36]. This species occupies nearly 40 % of the forests of Korea, which cover approximately 65 % of the total land area [17]. Though the trees attain considerable age and produce distinct datable growth rings, their dendroclimatic potential has not been extensively explored. A few studies have been conducted on this species to investigate the effect of air pollution on radial growth rates in Korea and Japan [14, 20, 24, 26, 35]. In these studies the effect of climatic factors on growth has not been well documented.

A previous study (Park and Yadav, unpublished data) on Korean red pine samples obtained from a xeric site in central Korea indicated that the growth of this species is strongly associated with spring precipitation. The present study is the extension of this earlier study to the south along the Korean Peninsula in order to test the feasibility of developing a tree-ring network of this species for regional-scale dendroclimatic studies.

1.1. Study area and climate

A natural stand of Korean red pine in the cool temperate zone growing on the northern slope (Hadong-Jangteomok area at 1 450 m, a.s.l.) of the Chiri mountain range was chosen for this study (*figure 1*). The sampling area was located just below the subalpine conifer zone, which is dominated by *Abies koreana* and *Pinus koraiensis* [33]. The broad-leaved zone found in valleys and on slopes is dominated by *Quercus mongolica*, *Fraxinus mandshurica* and *Acer* species, occasionally mixed with Korean red pine. Pure stands of Korean red pine are found on ridges. These isolated patches are separated from the Korean red pine zones at lower elevations (400–700 m, a.s.l.) [13, 33]. At lower elevations old Korean red pine trees are not found due to heavy human disturbances and occasional fires.

Climate over the southern Korean Peninsula is under both strong polar and tropical influences. During the winter, continental high-pressure air masses that develop over Siberia bring strong northerly cold dry air. The circulation reverses in summer and southerly winds bring warm moist air masses and monsoon rains. The summer monsoon (occurring mainly from June to August) contributes about 45–60 % of the annual precipitation. Winter precipitation accounts for about 3–10 % of the annual precipitation.

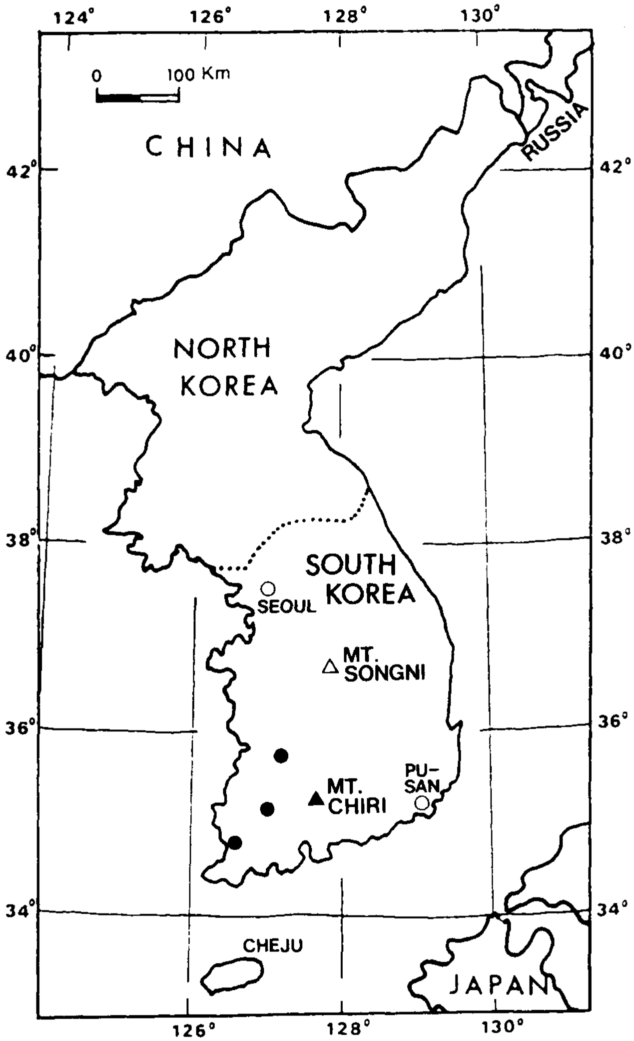

Figure 1. Map of Korea showing tree-ring sampling site (▲) and meteorological stations (●) used in the study the sampling site (△) for the previous study (Park and Yadav, unpublished data.

Weather records of the Chiri mountain experimental station (750 m elevation) for 1975–1986 [15] indicate that mean monthly temperature remains below 0 °C during winter (December–February) (*figure 2*). January is the coldest with a mean of –4.3 °C, while August is the hottest with a mean of 22.1 °C. Considering the lapse rate, January mean temperature at the sampling site (1 450 m) will be around –9.3 °C. July and August are featured by heavy monsoon rainfalls with the heaviest in August (425 mm). Total annual precipitation is around 2 030 mm. Considering the total annual precipitation and evapotranspiration, the area is classified as humid (B_4) zone [31, 34]. The study area experiences heavy snowfall during winter as is evidenced by the thickets of dwarf bamboo (*Sasa borealis*) on the slopes indicating deep winter snow cover [12, 23]. In this region where winds are

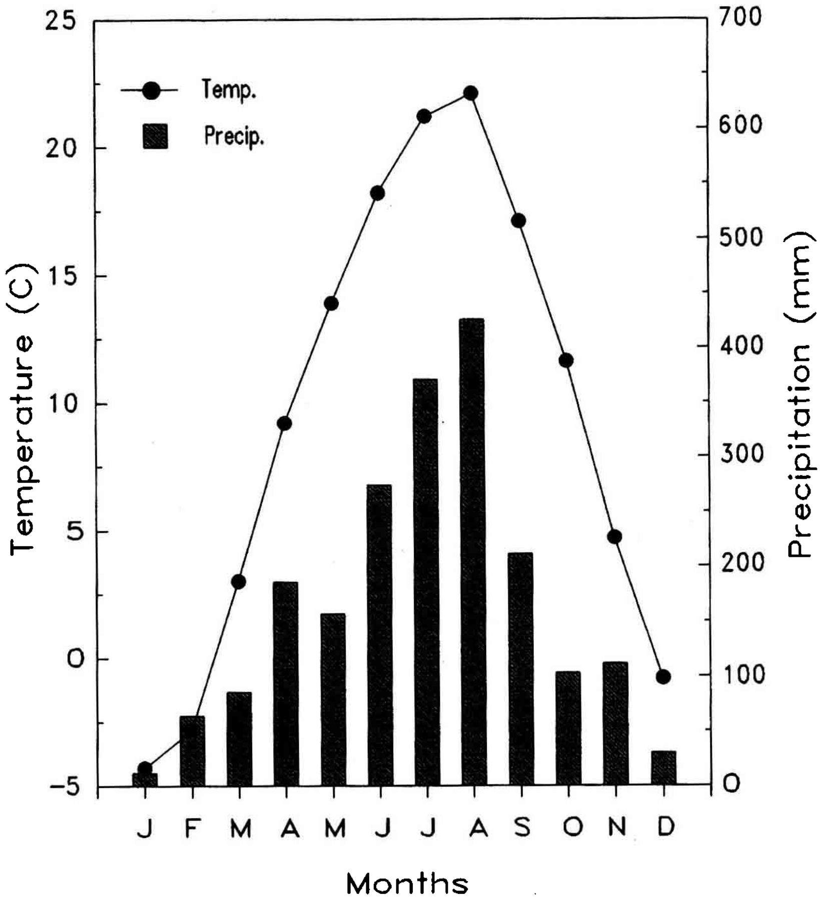

Figure 2. Plot showing the mean monthly temperature and monthly precipitation totals during 1975–1986 in Simwon Valley, Mt. Chiri (750 m, a.s.l.) in southern Korea (after [15]).

very strong dwarf bamboo cannot survive the winter without remaining covered by snow.

2. MATERIALS AND METHODS

2.1. Tree-ring data

A total of 31 trees constituting the dominant canopy trees were sampled during the autumn of 1996. Paired increment cores were taken at breast height using an increment borer. The sampled trees were carefully selected to avoid any visible defects or scars. The tree-ring sequences of the mounted and surfaced cores were cross-dated using the skeleton plot method [28]. After fixing the calendar date to each ring, ring widths were measured to the nearest 0.01 mm using a Velmex measuring system. Ring-width plots of each core (log scale) were produced from the ring-width measurements using the program TSAP [27]. These plots were used for visual comparison on a light table to cross-check the dating of sample cores within and between the trees. Another cross-check of dating and measurement accuracy was performed by correlating overlapping 50-year segments of all measured series using the program COFECHA [10]. This program helps in identifying segments of a core or group of cores for which dating or measurement errors might occur. Dating and measurements of a few samples that showed any ambiguity were verified and corrected. About 10 % of the cores for which such problems could not be corrected were excluded from further analysis.

Ring-width measurements were standardized to ring-width indices using the program ARSTAN [3]. Some trees showed non-synchronous patterns of suppression (narrow rings) and release (wide rings) that are probably related to stand dynamics. The detrending methods applied were chosen to remove age- and stand dynamics-related growth trends while preserving the maximum common high-frequency signal. In most of the cases the cubic spline with 50 % variance reduction function at 200 years was found suitable. However, splines of 120 or 60 years were selected for a few young samples. Each series was then prewhitened using an autoregressive model selected on the basis of minimum Akaike criterion [1, 9] and combined using a biweight robust mean [3]. The resulting residual chronology was finally prepared. The expressed population signal (EPS), a measure of correlation between the mean chronology derived from the sample of cores and the population from which they are drawn [32], was used to determine the adequacy of chronology replication for climatic investigation.

2.2. Climate data

Climate records of the meteorological station in proximity of the sampling site are very short – extending only two decades. Therefore, we prepared regional temperature and precipitation series (1908–1995) by merging the records from three homogeneous stations adjacent to the sampling site *(figure 1)*. Regional climate data also offer many advantages over single station data because problems associated with record inhomogeneities and differing station microclimates are reduced.

2.3. Tree growth–climate relationship

Reasonable chronology confidence was achieved in the residual chronology back to 1936 with the replication of 14 tree samples each year. Therefore, we used the chronology length from 1936–1995 (60 years) for tree growth–climate relationship analysis. The response function [5], which is a multiple regression technique using the principal components of monthly climatic data, was calculated for the chronology using the program PRECONK [7]. The monthly climate variables (mean monthly temperature and monthly precipitation totals) over an interval starting from September of the previous growth year and ending in September of the current growth year were used in the analysis. The PRECONK program calculates the response functions using the bootstrap method to obtain reliable estimates [8]. It repeats the calculation of response functions for the subsamples (calibration), which are randomly extracted with replacement from the initial data set. The size of each subsample is the same as that of the initial data set. For each subsample, an independent verification is done on the observations omitted from the subsample. We obtained final response functions and multiple correlation coefficient by averaging those of 50 subsamples.

3. RESULTS AND DISCUSSION

A 196-year (1801–1996) tree-ring chronology of Korean red pine was developed from the Chiri mountain range in southern Korea. Cross-dating of samples revealed that missing rings were rare; however, intra-annual bands or false rings were quite common, especially within the early growth rings. About 70 % of the sampled trees were around 100 years old and sample depth gradually declined beyond this point. The chronology was truncated at 1866 where EPS reached 0.75 with sample replication of 12 series from seven trees *(figure 3)*. Though individual trees of around three centuries have been collected in our previous study (Park and Yadav, unpublished data) from Songni Mountain in central Korea *(figure 1)*, the oldest tree

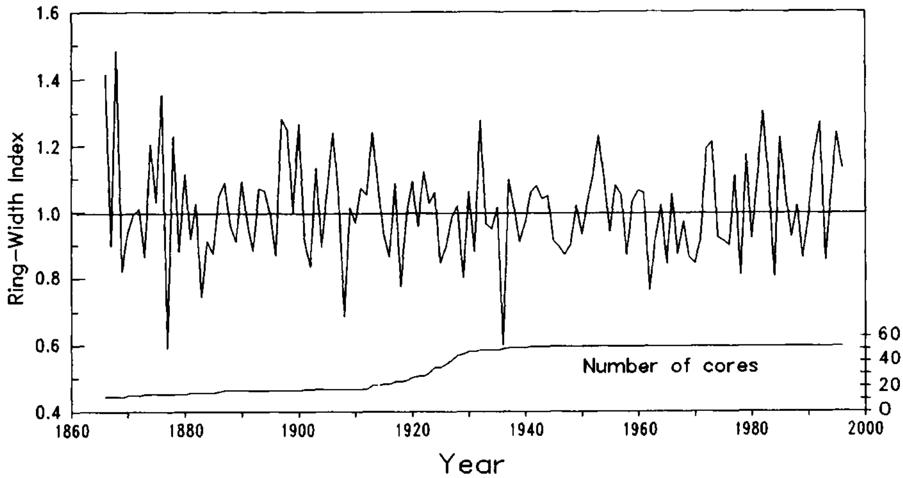

Figure 3. *Pinus densiflora* residual chronology (1866–1996) and sample depth (number of cores).

sample in our current collection reached to about 200 years. However, field surveys indicate that there exists the possibility of obtaining older trees on the ridges in the Chiri Mountains. The chronology statistics are summarized in *table I*. The chronology features such as between-tree correlation (0.34), signal–noise ratio (10.5), the variance explained by the first eigenvector (37.7 %) and measure of variance held in common between trees at the site indicate the potential of tree-ring chronology for dendroclimatic studies.

The response function analysis showed 56 % of the chronology variance attributable to climate. A direct relationship between radial growth of Korean red pine and January and March temperature prior to the growing season indicated in the response function *(figure 4)* suggests that the photosynthates produced during the dormant season play an important role in the growth of this species during the ensuing growth season. Similar to this finding, many evergreen conifers fix a considerable amount of their photosynthates during the dormant season [5, 19]. Another possible explanation could be due to root damage to superficial roots of Korean red pine trees caused by low winter temperatures. It may occur when snows are not dense enough to insulate the surface roots from the low atmospheric temperatures. As the roots are more temperature-sensitive in comparison to the aboveground stems [18], they are liable to be damaged by occasional freezing. The strongest relationship was found with March temperature. A comparison of ring-width indices with March temperature indicated that low and high index values are associated with a cool and warm March, respectively. The lowest index for 1936 is coincidental with the coolest March in the total span of meteorological record.

An inverse relationship between radial growth of Korean red pine and summer monsoon rainfall (June–August) is indicated in the response function. However, this is only significant for August. A possible explanation for an inverse relation-

Table I. Chronology (residual) statistics of *Pinus densiflora.*

Number of trees (cores)	27 (52)
Period (years)	1866–1996 (131)
Mean sensitivity	0.18
Standard deviation	0.15
Mean correlation*	
Among all radii	0.35
Between trees	0.34
Within trees	0.58
Signal-to-noise ratio*	10.5
EPS	0.91
Variance explained by first eigenvector	37.7 %

* Calculated for the common interval 1936–1996 (67 years); EPS, expressed population signal.

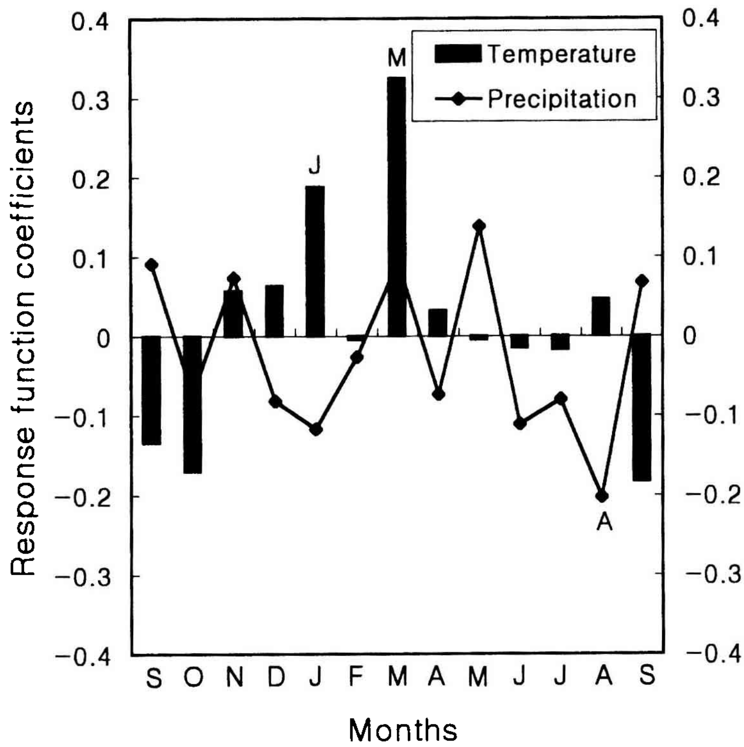

Figure 4. Response function for residual chronology with monthly climate variables (mean monthly temperature and monthly precipitation totals) during 1936–1995. Boot-strapped response functions were calculated for 13 months from the September preceding the growth year to the September ending the growth season. The significant coefficients at 95 % confidence level are indicated by the initial letters of the respective months.

ship between radial growth and summer monsoon could be the reduced solar radiation due to clouds and fog during this season. Frequent fogs and clouds, typical of a high mountain climate, are very common in the study area during the summer monsoon season [29]. Korean red pine trees usually prefer warm temperature and sunny days during summer [36]. In comparison to tree-ring indices and July–August solar radiations during 1970–1995, the lowest solar radiations of 1974 and 1993 were coincidental with the low indices, but other years (1978, 1984) could not be explained by solar radiation. Further study on solar radiation and growth measurements in the study area is needed.

The prominent direct correlation between the Korean red pine growth and spring precipitation noted at a dry site in central Korea at lower elevation (900 m) (Park and Yadav, unpublished data) was not observed in the present analysis. This may be due to site conditions of the present study. The present site is relatively mesic and located at a higher elevation where the soil moisture regime during spring is not as limiting for growth as at the xeric site of the previous study (Park and Yadav, unpublished data).

The existence of good cross-dating and strong tree growth–climate relationship noted in Korean red pine and its wide geographical distribution in Korea reinforce its potential for dendroclimatic studies.

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