DENDROCHRONOLOGY IN JAPAN

ENGLISH SUMMARY

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Contents

1 In this section,* and** respectively denote a "Historic Site" and a "Historic Site of Special Significance" designated by the national government.

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2 In sections 3 and 4,* indicates an "Important Cultural Property," **a "National Treasure."

List of Figures

3 In this chapter, by "per annum rainy days" we mean the total number of rainy days from April to September in each year.

List of Tables

Dendrochronology in Japan
English Summary

This report summarizes a research into dendrochronology and dendro-climatology conducted principally by archaeologist TANAKA Migaku 田中琢 and archeo-botanist MITSUTANI Takumi 光谷拓実 at the Nara National Cultural Properties Research Institute. The principal investigators are joined by SATŌ Tadanobu 佐藤忠信 of Disaster Prevention Research Institute at Kyoto University in the application of dendroclimatology. Our five year project initiated in 1985 has been supported by the Grant-in-Aid for Scientific Research program of the Japanese Ministry of Education. Prior to the presentation of our results, we first review previous research into the use of tree rings in Japan. We will proceed to discuss our studies, first on dendrochronology, and then on dendroclimatology.

Studies based on tree rings in Japan originally began with the aim of reconstructing palaeoclimate and the cycle of palaeoclimatic fluctuations. These measurements were calculated on the basis of the width of tree rings. However, such researches always utilized only one tree; the scholars did not attempt to cross-date more than one sample. This was the case in all pre-World War II studies.

The earliest example of dendroclimatological scholarship in Japan was HIRANO Ressuke's 平野烈介 research published in 1921. He calculated the total amount of growth of a *sugi* cedar based on the area of the cross-section of the tree. He observed fluctuations in the amount of yearly growth and determined that: "In the life of this particular Japanese cedar tree, we have clear evidence of a thirty-three year cycle." He identified this cycle as Brückner's cycle in climatology. Such studies were continued intermittently, and ohter hypothetical periodic cycles of long-term climatic fluctuation were proposed——110 years, 350 years, and 700 years. The most famous research was by YAMAZAWA Kingorō 山沢金五郎, then the director of the Weather Station at Takayama, Gifu Prefecture. In 1930, he published the result of his measurements of the width of 802 rings of a Japanese cypress tree (*Chamaecyparis obtusa* Endl.), and he attributed these 802 rings to the years between 1119 to 1920. In our re-examination, however, we discovered that these rings were formed between 1118 and 1919.

Among the pre-World War II scholars interested in dendrochronology, architectural historian SEKINO Masaru 関野克 was an exception in that he not only followed the progress in this field in Europe and North America, especially the achievements of A.E.Douglass who could indeed cross-date some floating chronologies, but also attempted to apply Douglass' work to Japanese trees. In 1943, Sekino measured the width of rings of structural parts of an eighth century building in Japan, and some of the ring patterns he drew still survive. Probably because of the social confusion and disturbances during and soon after World War Ⅱ, however, Sekino did not make any further progress in his research.

Another epochal study was published by SHIDEI Tsunahide 四手井綱英 and his collaborators in 1944. Their project, conducted in Akita Prefecture, was methodologically significant because they utilized measurements from several hundred Japanese cedars rather than just one tree. They concluded that the fluctuation in the tree growth between 1928 and 1942, as evidenced in the different width of tree rings, was related to the precipitation coefficient[1], the growth of Japanese cedar became poor whenever the precipitation coefficient went above or below certain values.

The majority of postwar tree ring studies in Japan were climatological. Scholars became methodologically precise and were no longer satisfied with simple comparisons between ring patterns and climatic fluctuations. Nonetheless, meticulous data-gathering such as characterized Shidei's work was not yet common.

Two studies conducted during that period were worthy of note. One was TAKAHASHI Hiroaki's 高橋宏明 study. Following Shidei's example, Takahashi explored the relationship between tree growth and climatic factors, especially precipitation coefficient. He showed the correlation among the average width of rings of several trees at one specific site and the average width taken at different sites. The fact that trees of different ages and at different localities showed the same growth pattern indicated the connection with a common environmental factor—climate. This was the starting point of his research. Unfortunately, no scholars continued this line of research and thinking.

Another interesting study was conducted by NISHIOKA Hideo 西岡秀雄, who set out to date an architectural structure using dendrochronology. He measured the width of approximately 250 rings of the central pillar of the pagoda at Hōryū-ji 法隆寺, Nara Prefecture, the oldest surviving wooden structure in the world. He then compared the measurements with a ring pattern taken from a part of a different structure built in the 730s also at Hōryū-ji and concluded that the tree used in making the Hōryū-ji pagoda pillar was cut down before 607. Nishioka's work was significant because it

1 The ratio between amount of annual precipitation and annual average temperature

was the first use of tree-rings for the purpose of dating. Nonetheless, both tree samples from which he took ring patterns lacked the outer most part of the bark, which would have given precise dates of trees cut down. Consequently, Nishioka's work has been regarded by later scholars as hasty and imprecise and has been duly ignored.

Part of Japanese negative attitude toward dendrochronology came from scholars' belief in the impossibility of its application to Japanese trees. They believed without any testing that the climate and topography in Japan were so different from Arizona where Douglass developed dendrochronology that what was possible in Arizona would not be possible in Japan.

What tempted us to pursue dendrochronology at the Nara National Cultural Properties Research Institute was that we had excavated numerous wooden artifacts at archaeological sites. We had also conducted ethnographical/historical field research into a number of ancient temples, shrines, and other old wooden structures. Our knowledge about European and American achievements in this field also stimulated our research.

In 1970, one of our colleagues started to measure tree ring width. After he processed some samples, he reached the conclusion that it would be very difficult to apply dendrochronological methods to Japanese cypresses. Since most buildings in Japan were traditionally made from cypresses, the project was halted.

In 1979 we started a preliminary research and found the application of dendrochronology and dendroclimatology to Japanese trees possible. In 1985, our major studies in these two fields began, and we confirmed the possibility of the application of dendrochronology to archaeology, history, architectural history, and art history. We also made considerable progress in dendroclimatology. At the same time of our research, other dendrochronological studies were published. Our studies could be distinguished by the fact of having established a significantly long-term ring pattern.

The method for cross-correlation of tree-ring patterns that we used was basically same as that of Europe. In order to standardize the varying tree ring width, we used the five running mean method. To determine statistical significance, we used Student's "t" test. With sixty or more degrees of freedom, we compared the obtained t value with the 0.1 per cent significance level of t, which was 3.5. Correlations of ring patterns which grew over the same span of years normally produced t values greater than t =3.5. Our experience showed that samples in a pair which yielded a t value greater than 3.5 did not necessarily cross-correlate. We always double-checked with the results of visual matching of pattern graphs with reference to key signature patterns. The statistical calculations were simply a means of cross-correlating ring patterns.

The materials were taken from living forest trees, old structures, and wooden artifacts discovered at sites. The kinds of trees used in our studies included: a *hinoki* cypress *Chamaecyparis obtusa* Endl., a *sawara* cypress *Chamaecyparis pisifera* Endl., an *asunaro* arborvitae *Thujopsis dolabrata* Sieb. et Zucc., a *hiba* arborvitae *Thujopsis dolabrata* Sieb. et Zucc. var. Hondai Makino, a *kurobe* arborvitae *Thuja Standishii* Carr., a *tsuga* hemlock *Tsuga sieboldii* Carr., a *sugi* cedar *Cyptomeria japonica* D. Don, and a *kōyamaki* pine *Sciadopitys verticillata* Sieb. et Zucc. all of which were coniferous trees, as well as some deciduous trees, such as a *mizunara* oak *Quercus mongolica* Fischer ex T. var. *grosseserrata* (Bl.) Rehd. et Wils. and a *buna* beech *Fagus crenata* Bl..

The first step of our dendrochronological studies was to confirm the applicability of dendrochronology to Japanese trees and to determine an appropriate species for our studies. For the first purpose, we selected a Japanese cypress because it was native to Japan, and natural forest of this tree was distributed from the southern half of the Honshu island to southern Kyushu. Cypresses had also been most widely used for Japanese architecture, and were often discovered at archaeological sites. Utilizing modern Japanese cypress trees, we recognized the following features important for our studies: 1) ring patterns taken radially from the same tree tended to highly correlate with each other; 2) rings formed during trees' early life tended to show features unique to individual trees, this leading to the intelligence that for dendrochronological studies we should avoid rings near the center of a tree; 3) rings near or at the base of a tree often showed anomalies because of the expansion of the root; 4) given a certain region, rings of different trees showed very high correlations to one another. We could even cross-correlate samples taken from trees approximately 400 kilometers apart.

For the second goal, we tested a *kōyamaki* pine, a *sawara* cypress, an *asunaro* arborvitae, a *hiba* arborvitae, a *kurobe* arborvitae, a *tsuga* hemlock, a *sugi* cedar, a *mizunara* oak, related species of which were widely used in European dendrochronological studies, and a *buna* beech which was the most representative deciduous trees in Japan. Among these, we found the first seven species suitable for our studies. It is ironic that the last two species were not found to be applicable.

The next step was to build an index master chronology, which was the foundation of any dendrochronological studies. Our index master chronology of *hinoki* cypress trees spanned from 317, B.C. to 1984. It was derived from: Standard Chronology A(1695-1983) taken from a modern tree; Standard Chronology B (1027-1755) taken from a structural part of a sixteenth century building at Tōdai-ji 東大寺, Nara; Standard Chronology C (751 - 1591) derived from artifacts discovered in the Kiyosu 清洲 Castle Town site (fifteenth and sixteenth centuries), Aichi; Standard Chronology D (512 - 1322) derived from artifacts descovered at the Toba 鳥羽 Detached Palace (eleventh and twelfth centuries) site, Kyoto and those at the Kusado Sengen-chō 草戸千軒町(Medieval Age) site, Hiroshima; Standard Chronology E (37,B.C.-A.D.838) derived from artifacts discovered in the Heijō 平城 Capital (710-784) site, Nara; and Standard Chronology F (317,B.C.-A.D. 258) derived from artifacts discovered at the Yayoi (fourth century, B.C. to A.D. third century) and Kofun (fourth to sixth centuries) sites.

We also built chronologies derived from *sugi* cedar trees, but none of them overlapped with one another. They were: Standard Chronology A (17 79 - 1986) taken from a modern tree; Standard Chronology B (405 - 1285) taken from artifacts discovered at sites in the Tohoku District and cross-correlated with the Index Master Chronology of cypress; and Standard Chronology C (420,B.C.-A.D.265) derived from artifacts discovered at sites in the Tokai region (the Pacific Coast of the Chubu District) and cross-correlated with the Standard Chronology F of cypress.

In addition, we built two Chronologies utilizing *kōyamaki* pine trees. A 556 year ring pattern derived from artifacts discovered in the Heijō Capital cross-correlated with the Standard Chronology E of cypress and spanned from A.D.186 to 741. In the same way, an artifact discovered at the Shijō Kofun 四条古墳 burial site in Nara gave rise to a chronology between 286 and 695.

We then applied these chronologies to artifacts, early architecture, and crafts in an attempt to date them. Here are some examples: the Shijō Kofun, Nara, the Seta no Kara Hashi 瀬田唐橋 Bridge site in Shiga Prefecture, the Miyamachi 宮町 site, Shiga Prefecture, and the Hotta no Saku 払田柵(Hotta Fort) site in the present Iwate Prefecture.

At the Shijō Kofun, 448 was the latest dendrochronological date obtained from numerous artifacts made of *kōyamaki* pine, which had presumably been used for mortuary rituals, and were discovered in the moat surrounding the Kofun. In other words, the Kofun was built sometime after 448. Since the absolute dating of *kofun* or burial mounds built between the late third and sixth centuries had always been debated, we believe that dendrochronology would be a useful method by which to determine absolute dates.

We applied dendrochronology to try to estimate when a bridge was built for the first time over the Seta River. Archaeologists excavated structures of a bridge near the present Seta no Kara Hashi Bridge 3.5 meters below the bottom of the River. We utilized several long pieces of timber and lumber of 20 to 50 centimeters in diameter or in length. We confirmed that the bridge was constructed after 607, and consider it probable that this was the strategic bridge the control over which was an important aspect of a civil war in 672.

A ring pattern taken from the lower portion of a wooden pillar discovered at the Miyamachi site cross-matched with the Standard Chronology E of cypress, and we could confirm that the tree for the pillar was cut down between 742 and the beginning of 744. This made it very highly likely that the site was a part of the Shigaraki 紫香楽 Palace which was occupied from the eighth month of 742 (on the lunar calender) and the fifth month of 745.

In the same way, we could determine that the construction of the Hotta no Saku 払田柵 was begun between 801 and 802. There was a cross-matching of ring patterns yielded from logs of cedar (a square of approximately 30 centimeters in length) which surrounded the site and the Standard Chronology B of cypress. This refuted the hypothesis that the site was the historically known Okachi 雄勝 Castle built in 759.

Our study of dendrochronology made considerable contributions to architectural history and art history as well. Examples of dendrochronological applications included Hōryū-ji, a Nara Period horse painting, a Kamakura Period guardian figure at Tōdai-ji 東大寺, Buddha figures in Yamaguchi Prefecture, Ha'ushiwake 波宇志別 Shrine in Akita Prefecture, Wakamiya Hachiman 若宮八幡 Shrine in Nagano Prefecture and a Medieval wooden bent-box in Kyoto:

We applied dendrochronology to date the western complex of the Hōryū-ji. There had been two major hypotheses concerning the dating of Hōryū-ji: a) the temple was built around 610 during the reign of Empress Suiko 推古; and b) the temple was burnt down around 670 and rebuilt at the end of the seventh or the beginning of the eighth century. The number of rings of the central pillar of the pagoda in the western complex was 351, corresponding to the years 241 to 591. The pillar had been extensively modified from the original tree trunk by largely removing the exterior portion and the central portion; it would be unlikely that only the outermost twenty rings were removed for this modification. We found it very unlikely that the pagoda was built during the reign of Empress Suiko around 610.

Next, we were able to give a more specific date to a small painting. In 1989 we discovered in a garbage pit in the Heijō Capital a painting of a horse done on a cypress board of 27 by 19.5 centimeters and 0.7 centimeters in thickness. Since this board still kept the most exterior portion of the original tree, we could date the outer most ring to the year 728. We could also date the pit to 737 by a wooden tablet with a dated inscription. The horse was probably painted between 728 and 737. This dating was felicitous because the horse was one of the few surviving examples of the eighth century paintings in Japan.

Next, our ability to achieve this degree of specificity in dating, we could confirm a historical record. In 1181, one year after Tōdai-ji was burnt down in a civil war, priest Chōgen 重源 and his collaborators began to reconstruct the temple. Two gigantic guardian figures (4.5 meters in height), housed in the south gate of the temple, were built between the seventh month and eleventh month of 1203 (on the lunar calendar). In 1989, there was an overhaul of one of the figures, so we took the opportunity to apply dendrochronological dating to the parts of the figure which still retained bark. Original trees utilized for this statue were cut down in the winter of 1196, 1199, and 1201 or during the following spring of those years. Further, we discovered that one of the ring patterns taken from the statue was almost identical to that of a Buddha figure in the present Yamaguchi Prefecture— approximately 400 kilometers apart. Since it was historically known that Chōgen brought timber for structural parts of the temple, it was quite likely that wood for the guardian figures also came from Yamaguchi.

In other cases, finally, dendrochronological dates could contradict dates determined according to stylistic evolution. In and the vicinity of the Tokuchi 徳地 Town, Yamaguchi Prefecture, there were many Buddha figures in various temples, which were stylistically dated to the late twelfth century. We applied dendrochronology to fifteen of them and discovered that the most recent rings of trees used in six of the figures were formed in the 1190s. Since the exterior portion, and in some cases the central portion of trees, had largely been removed, the trees must have been cut down in the *thirteenth* century. The earlier dating should be reconsidered.

Structural parts of the Kagura-den 神楽殿 (Hall of Ritual Music and Dance) at the Ha'ushiwake Shrine yielded dendrochronological dates of 1177 and 1195 by cross-matching with the Standard Chronology B of cedar. Since both of the structural parts kept the bark, the original trees were cut down around that time in the twelfth century. According to stylistic criteria, the Kagura-den had been estimated to date from the fifteenth century. When these Shrine structures are overhauled sometime in the future, we should more thoroughly investigate the dates of the structures by apply-ing dendrochronology.

Similarly, major pillars of the Hon-den 本殿(Main Hall) at the Wakamiya Hachiman Shrine were dendrochronologically dated to be after 1614, the structure was stylistically considered to be of the Momoyama Period (1582-1600).

Further, this method was effective in detecting forgeries. A certain temple in Kyoto Prefecture owned a wooden bent-box of cypress (a cylindrical container) which had the inscription dated to 1233 on the bottom. We discovered, however, that the most recently formed tree-ring was dated to 1576. The container was a forgery !

In addition to architectural structures, art objects, and artifacts, dendrochronology is effective in dating natural disasters. A standing *hinoki* cypress of 1.4 meters in diameter with the bark completely preserved was discovered underground in the Susono 裾野 City at the foot of Mt. Fuji 富士. Taking the topography of the vicinity into consideration, it was probable that lava issuing from an eruption of Mt. Fuji dammed up a river, thereby submerging the whole forest and killing the trees. If this was indeed the case, we could estimate the date of an eruption of Mt. Fuji. By cross-matching with the Standard Chronology E of cypress, we could date the standing tree to A.D.833.

Similar discoveries of buried forests which might indiate natural disasters were reported from all over Japan. In the Mamurogawa 真室川 Town, Yamagata Prefecture, some twenty cedar trees were similarly discovered six meters below the ground. By cross-matching with the Standard Chronology B of cedar, we confirmed that the most recent ring was formed in A.D.850. In other words, a natural disaster which buried a forest hit this area between the winter of 850 and spring of 851.

In Futatsu'i 二ツ井 Town, Akita Prefecture where the people believed in a tale that several thousand *koku*[2] of wild cedars were buried by a landslide during the Tokugawa Period (1600-1868), numerous large trunks of cedars and Japanese oaks of approximately 1.5 meters in diameter were discovered a few meters below the ground. We dated 754 rings of a cedar tree by cross-matching with the Standard Chronology A of cedar and discovered that the most exterior ring was formed in A.D.958. The forest was buried in the middle of the tenth century, much earlier than the people believed.

2 a unit of volume used widely in Japan before the Meiji Restoration of 1898; in the case of trees, one *koku* equaled to 0.278 cubic meters.

In the southern part of Akita Prefecture, there was an area where a large forest was buried more than ten meters below the ground. Most of the trees were cedar and some exceeded four meters in diameter. Taking into consideration the soil of the area and the way in which the trees had fallen, we hypothesized that an enormous mud flow resulted from an eruption of Mt. Chōkai 鳥海 some ten kilometers southeast of the forest. Radiocarbon dates showed that the disaster happened abound 2600 B.P. We applied dendrochronology to eight somples taken from the buried forest, six of which were with barks completely preserved. The most recent rings were formed at the some time; it was likely that one eruption caused this complete destruction. The fact that the most recent rings contained fully mature cells indicated that the eruption occurred sometime between the winter of a certain year and the spring of the following year. We derived a ring pattern which spanned 848 years, but it remained as a floating chronology; it was too old to be cross-matched with any standard chronologies. Once we extend our Index Master Chronology to 2600 B.P., we could confirm the precise date of this disaster.

In addition to the dendrochronological advances discussed above, we progressed in the application of dendroclimatology. The ring pattern we used was derived from thirty samples of living cypress trees in Nagano Prefecture and the Standard Chronology B which was presumably based on timber produced in the same prefecture. We also collected the data concerning the number of rainy days from April to September in each year for the past 170 years from a local weather station and from diaries kept by local people before the weather station started. We filled missing data (years for which we did not have records of rainy days) by a one-dimensional autoregressive process. We discovered that our reconstructed 170 year-long data of rainy days per annum[3] closely corresponded to the current precipitation data in Nagano Prefecture. We concluded that the number of rainy days was appropriate for climatic data.

In order to determine the most influential climatic factor in tree growth, we tried correlating the number of rainy days and average temperature to tree ring width. Tree grew fastest when there were many rainy days temperature did not rise.

We then compared the power spectra of treering width and of the per annum rainy days. We discovered cycles of approximately six years, eight

3 Throughout this section, by "per annum rainy days" we mean the total number of rainy days from April to September. Such data sets were chosen as the climatic data because tree rings grow most from spring to fall.

years, and twenty-three years to be common to both sets of data. This indicated to us a very good correlation between the tree ring width and per annum rainy days.

Owing to this correlation, we proposed a system in which climatic data represented by per annum rainy days were input and tree ring width data were output, by the process of an autoregressive moving average function. In order to identify per annum rainy days from the tree ring width data, we developed a correlation function. The most effective function for this purpose was a process with three autoregressive and two moving average coefficients. Using the identified parameters of this process,we reconstructed the per annum rainy day for eighty years beginning in 1760. We derived the relationship between the tree ring width data and per annum rainy days from 1009 to 1984, assuming the linear system we had used previously between the two factors. We standardized the primary tree ring width data for these 976 years by the spline function. We used the Kalman filtering algorithm, including the U-D observation updated theorem, to identify the system parameters. In the process of parameter identification, every parameter gradually converged to a certain value.

By utilizing these system parameters, we calculated per annum rainy days for the 170 years for which we originally had good weather records. Our calculation was in basic agreement with the actual data. In the same way, we could reconstruct the per annum rainy days for approximately 800 years before 1813. These results of our research showed that the application of dendroclimatology was possible in Japan.

Another major contribution of our research was the applicability of dendrochronology and dendroclimatology to Palaeolithic samples. At the Tomizawa 富沢 site, Sendai City, Miyagi Prefecture, excavators discovered features three meters below the ground, which suggested that the inhabitants had been manufacturing stone tools at a camp fire. We could build a ring pattern spanning 323 years, derived from cross-correlation of three samples of genus *Larix* (a kind of larch). Since the site was dated by carbon 14 to have been more than 20,000 years old, we could not dendrochronologically determine the date of the site, as our Index Master Chronology did not extend beyond 317,B.C. Nonetheless, this result showed the potential application of tree ring studies to the Palaeolithic Period.

In summary, our ten year project (including the preliminary research started in 1979) has shown that the application of dendrochronology and dendroclimatology to Japanese trees is possible. Our Index Master Chronology of cypress extends back to 317,B.C. The Master Chronology of cedar of the Tohoku District extends to A.D.405, and that of cedar of the Pacific Coast of the Chubu District to 420,B.C. We have certainly progressed to the stage of application to other disciplines such as archaeology, architectural history, art history and the history of natural disasters in Japan.