Stem Analysis of a Pollarded Wild Sugi (*Cryptomeria japonica*) Tree

Satoshi Tatsuhara¹*, Keigo Tanaka¹, Koji Yamada², Hiromi Akashi² and Kimio Takeuchi²

ABSTRACT

This study proposes a way to apply stem analysis to pollarded trees and to show the relationship between the growth of a pollarded tree and topping the main trunk. As an example, we examined a pollarded wild sugi (*Cryptomeria japonica*) tree. The study tree was in a sugi plantation with scattered wild sugi trees in Tsunagi hamlet, Aga Town, Niigata Prefecture, Japan. The main trunk was thought to have been broken by heavy snow. The part of a coppiced tree that differs most from a single-stemmed tree is the area that connects the remaining trunk and the pollard shoots. Examining disks taken by slicing through part of the tree allows the budding location and timing of the formation of the shoots to be determined from the distribution of annual rings. This study showed that losing the upper part of the trunk had a great effect on the secondary growth of the remaining trunk, suggesting that topping a main trunk also affects the secondary growth of the remaining trunk. Competition between the shoots was found, suggesting that in order to obtain large, high quality logs from the remaining trunks, shoots that are likely to die are pruned before they put on much growth.

Keywords: *Cryptomeria japonica*, growth, pollard, pollard shoot, stem analysis

INTRODUCTION

The ‘daisugi’ system which is practiced in the Kitayama area, Kyoto, Japan, involves pollarding of sugi (*Cryptomeria japonica* D. Don): The trees are pruned 5–6 years after planting leaving only branches at about 0.6 m above the ground, above this the trunks are cut and pollard shoots allowed to grow from the remaining trunks; The shoots are selectively harvested, producing a standard size that is used for building materials (Shigemoto, 1950). In areas with heavy snow in the Tohoku region and Niigata Prefecture, Japan, there are pollarded beech (*Fagus crenata*) trees with multi-forked trunks that branch more than 2–3 m above the ground (Nakashizuka et al., 2000; Suzuki, 2019). Scattered populations of pollarded wild sugi trees in Otokoro hamlet in Itoigawa City and Tsunagi and Nakanosawa hamlets in Aga Town, Niigata Prefecture, Japan, have a similar tree form to the ‘daisugi’, with multi-forked trunks that branch more than 2 m above the ground (Tatsuhara et al., 2017; Tatsuhara et al., 2020). Suzuki (2019) found rapid growth in terms of diameter in a disk taken from the remaining trunk of a pollarded wild sawara cypress (*Chamaecyparis pisifera*) tree and pointed out that cutting the main trunk stimulates the growth of the trunk that is left; thus, the pollarding system for wild sugi trees in the Katanami River headstream area is suited to obtaining large boards from the remaining trunks.

Ghahramany et al. (2017) assessed the effect of pollarding on the diameter growth of Lebanon oak (*Quercus libani* Oliv.) trees in Northern Zagros, Iran by measuring sample trees in a pollarded stand with sample trees in a less-disturbed stand. Dufour et al. (2018) also assessed the effect of pollarding on the diameter and height growth of hybrid walnut trees by examining pollarded trees and control trees four years after pollarding. Suzuki (2019) demonstrated a change of diameter growth with increment cores from remaining trunks and pollard shoots of wild sawara cypress trees. However, the growth of pollarded trees has rarely been studied in detail.

In this study we aimed to propose a way to apply stem analysis to pollarded trees and, using such analysis, to examine the growth of a wild sugi tree that has lost the upper part of its trunk. We examined the effect of losing the upper part of a trunk on the growth of the remaining trunk and the relationships between the growth of different pollard shoots.

* Corresponding author. E-mail: tatsu@fra.a.u-tokyo.ac.jp

¹ Graduate School of Agricultural and Life Sciences, the University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan

² Specified Nonprofit Corporation “Forest Tree School in the Mountain”, 1344-4 Nakanosawa, Aga Town, Higashi-kanbara-gun, Niigata 959-4611, Japan

© **** Japan Society of Forest Planning

DOI: 10.20659/jfp.2021.001
METHODS

Study Site

The study site was a sugi plantation with additional scattered wild sugi trees in Tsunagi hamlet, Aga Town, Niigata Prefecture, Japan (37° 48' N, 139° 26' E). This stand used to be a hardwood secondary forest with scattered wild sugi trees. In 1978, hardwood trees were harvested by clear-cutting and the wild sugi trees were left. There are no records that wild sugi trees were cut except trees with trunks damaged by snow.

In this hamlet, charcoal making was the main source of cash income until around 1965, and hardwood secondary stands used to be clear-cut in a 15 to 25 year-rotation (Tatsuhara et al., 2020). Nobody has reported pollarding of wild sugi in this hamlet (Tatsuhara et al., 2020). All forests in this hamlet are owned privately. Because the hamlet’s commons were incorporated into the national forest in 1875, this hamlet initiated a lawsuit to get the forests back from the government in 1890, which they won in 1898 (Nihei, 1995).

Stem Analysis Procedure

A pollarded tree was divided into three parts: the remaining trunk, the pollard shoots, and the area between the remaining trunk and the pollard shoots. (i) Two disks are taken from the remaining trunk part; one from the bottom and one from the top part where it was unaffected by the shoots. The annual rings of the disks are measured. (ii) A reference level was set for each pollard shoot. Disks were taken from the shoots as if they were single trees and the reference levels were considered to be 0 m. Disks were taken from each shoot at the reference level, 1 m from the reference level, then at 2-m intervals above this and to within 3 m of the end of the shoot; in the final <3 m section, disks were collected every 1 m. The last part was sampled differently to the standard method used in Japan, that is, if the final section after the 2-m interval samples was less than 3 m, a single additional disk was taken 1 m along the stem (Osumi, 1987). Annual rings on the disks were measured. (iii) Some disks were taken from the part between the remaining trunk and shoots by slicing into it; annual rings were not measured but just counted because more than one stem is merged in each disk, so the shapes of disks and annual rings are complex and they vary greatly with height above the ground. Annual rings on both sides of the disks were counted in order to obtain more information with the same number of samples.

Practicing Stem Analysis

We chose one pollarded wild sugi tree in the stand (Fig. 1), and carried out stem analysis of the tree following the procedure described above. The tree was cut down and disks were taken from the tree on 13th September, 2019. According to the owner of this stand, the main trunk was broken by heavy snow. After the tree was cut, disks D0 and D1 were taken from the remaining trunk at 0.15 m and 1.13 m above the ground, respectively. The height 1.13 m was chosen because, at this point, the bulge caused by the shoots had little effect on the diameter of the remaining trunk. Three disks of D2, D3, and D4 were taken from the section between the remaining trunk and shoots, which was between 1.13 m and 2.13 m above the ground. The heights of either side of disks D2, D3, and D4 were 1.43 m and 1.53 m, 1.73 m and 1.83 m, and 2.03 m and 2.13 m, respectively. The tree had four live shoots and three bases of dead shoots. The live shoots were numbered from 1 to 4 clockwise starting from the direction of the highest ground. The reference level (0 m) for each shoot was set at its base, which was as low as possible and as straight as possible. For each reference, the height above the ground was measured. Disks were then taken according to the procedure above. The dead shoots were numbered M1 to M3 clockwise starting from the direction of the highest ground.

Disks D0 and D1 and disks from the shoots were scanned at 300 dpi with an Epson ES-G11000 flatbed scanner and the widths of annual rings in the image files were measured with Dendro Measure (Nobori, 2005). Diameter and cross-sectional area for each year and each disk were calculated. Total height of the main trunk before it reached 1.13 m tall and height from the reference level of each shoot in each year was calculated using Stem Density Analyzer (Nobori et al., 2004). Volume for each year was calculated from cross-sectional area and total height. Pictures of both sides of disks D2, D3, and D4 from the area between the remaining trunk and the shoots as well as the upper side of D1 were taken with a Sony α NEX-5N digital camera. When annual rings were counted, the calendar year and the age when the main trunk and shoots reached the disk’s height were determined.
Estimating the Year When the Main Trunk was Broken and its Height and Diameter outside Bark in that Year

The calendar year and age when the main trunk reached the height of each disk were determined from the difference in the number of annual rings between disk D0 at 0.15 m and each measured disk. We counted the number of annual rings of the remaining trunk from the uppermost disk for which the calendar year could be determined. Then the calendar year in which the main trunk was broken was estimated by adding the calendar year to reach the height of the uppermost disk to the number of annual rings in the remaining trunk in the uppermost disk at height above the ground as follows:

\[ y = y' + n, \]  
\[ h = l + g \times n, \]  
where \( y \) is the calendar year in which the main trunk was broken, \( y' \) is the calendar year to reach the height of the uppermost disk, and \( n \) is the number of annual rings in the remaining trunk in the uppermost disk. The height where the main trunk was broken was estimated as follows:

\[ h = l + g \times n, \]  
where \( h \) is the height at which the main trunk was broken, \( l \) is the height in calendar year \( y' \), and \( g \) is the annual height increment.

Furthermore, the diameter at 1.13 m in the year when the trunk was broken was estimated. Once the year had been estimated, the diameter inside the bark at 1.13 m in that year was determined. Knowing the bark thickness is necessary to estimate the diameter outside the bark from the diameter inside the bark. To estimate the ratio of the bark thickness of both sides to the diameter inside the bark (hereafter bark thickness ratio), the following equation was applied to the measurements of the diameter inside the bark and the bark thickness ratio of the disks from the four living shoots:

\[ BTR = \frac{DIB}{\alpha}, \]  
where \( BTR \) is bark thickness ratio and \( DIB \) is the diameter inside the bark. This equation was originally used to express the relationship between DBH and the mean bark thickness percentage at breast height (Nakayama, 1957). Next, bark thickness of both sides of the trunk at 1.13 m was estimated from the diameter inside the bark at 1.13 m with Eq. (3). The diameter at 1.13 m was estimated by adding the bark thickness of both sides to the diameter inside the bark.

Finding the Inflection Points in the Growth of the Tree

We determined one-year increments for the diameter and cross-sectional area at 0.15 m and 1.13 m on the main trunk and at the reference height for the four shoots as well as one-year increments of the heights of the main trunk and the four shoots from the stem analysis. Five-year increments were calculated from the one-year increments and plotted on graphs to display the growth trends in terms of diameter, cross-sectional area, and height. After identifying inflection points in the trends of periodic annual increments, we calculated regression equations based on the one-year increments before and after these points, then tested whether the regression coefficient after the point was statistically larger than the one before the point according to the \( t \)-statistic, as follows:

\[ t = \frac{a_1 - a_2}{\sqrt{s_1^2 + \frac{1}{S_{y1}^2}}}, \]  
where \( a_1, S_{y1}, s_1, \) and \( n_1 \) are the regression coefficient, the sum of the deviation squares of \( y \), the sum of the deviation squares of \( y \), the multiple regression coefficient, and the sample size of the \( i \)-th measurement group (\( i = 1 \) before the inflection points or 2 after the inflection points) (Tomita and Uchiyama, 2004). When inflection points in the trends of total increments was found, we calculated the average of one-year increments before and after the inflection points, then we examined whether the average of the increments after the point was statistically larger than that before the point using Welch’s \( t \) test based on the following statistic:

\[ t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{s_1^2 + s_2^2}}, \]  
where \( \bar{x}_1, s_1, \) and \( n_1 \) are the average, unbiased variance, and sample size of the \( i \)-th measurement group (\( i = 1 \) before the inflection points or 2 after the inflection points).

RESULTS

Measurements of External Form

The girth of the study tree was 2.55 m at 0.8 m above the ground and its total height was 25.14 m. The heights, the heights to the bottom of the crown, and the reference levels of live shoots were measured and the locations of the three dead shoots were recoded (Table 1). Both live and dead shoots grew straight up. The tree had frost crack, which it made it difficult to count and measure annual rings on some disks.

Estimating the Year When the Main Trunk was Broken and its Height and Diameter outside Bark in that Year

There were 152 annual rings in disk D0 at 0.15 m and the
central ring of the disk was found to have formed in 1868. Although the actual tree age is 152 plus the number of years it took the tree to reach 0.15 m, the tree was regarded as being 152 years old. There were 127 annual rings in the main trunk on disk D1 at 1.13 m, and 120 annual rings in the main trunk on upper side of disk D3 at 1.83 m and the upper side of disk D2 at 1.53 m. The total height in 1893 and 1900 was determined to be 1.13 m and 1.83 m, respectively. Annual rings of the main trunk were not counted on the lower side of disk D3 at 1.73 m and the lower side of disk D2 at 1.43 m because of damage caused by frost cracking. The average annual height increment was 0.05 m during the five years just before the main trunk reached 1.13 m tall in 1893. The 6-year increment was estimated to be 0.3 m just after main trunk reached 1.13 m tall by multiplying 0.05 m by 6. It was for 6 years to grow from 1.13 m to 1.43 m on height. Main trunk was estimated to be 1.43 m in 1899. Because this value was less than 1.53 m and consistent with the fact that the total height had already reached 1.53 m during the growth period of 1900, the total height in 1899 was determined to be 1.43 m. The annual height increment in 1900 was calculated to be 0.4 m·year⁻¹. There were 9 annual rings (n) of the remaining trunk in the uppermost disk at the height of 2.13 m (l). The calendar year when the main trunk reached 2.13 m tall was estimated to be 1901 (l'), based on the height difference between the two disks at 1.83 m and 2.13 m and the annual height increment of 0.30 m·year⁻¹ (g), and the total height in 1901 was estimated to be 2.13 m. Therefore, the main trunk was estimated to have been broken as a result of heavy snow accumulation in 1910 (j) at 4.83 m (h), according to Eqs. (1) and (2). The age of the tree was 43 years from 1899 to 1900.

In 1910, the diameter inside the bark was 11.4 cm at 1.13 m. Parameters α and β of Eq. (3) were determined to be 0.166 and −0.381, respectively, and the bark thickness ratio and the bark thickness of both sides at 1.13 m were estimated to be 0.0657 and 0.75 cm, respectively. The diameter outside the bark at that height was estimated to be 12.2 cm, based on adding the bark thickness to the diameter inside the bark. The tree was 111 years old when hardwood trees were harvested and sugi seedlings were planted in the stand in 1978.

Secondary Growth of the Remaining Trunk and Primary Growth of the Pollard Shoots

The cross-sectional area increment at 0.15 m increased rapidly around the time when the main trunk was broken, followed by an increase in the cross-sectional area increment at 1.13 m around the age of 90 years (Fig. 2). Statistical tests showed the regression coefficients for the cross-sectional area increment at 0.15 m and 1.13 m to tree age were significantly different at the ages of 49 years and 88 years, respectively (Table 2). The diameter increment at 0.15 m also increased rapidly around the time that the main trunk was broken, and statistical tests showed the regression coefficients of the diameter increment at 0.15 m to tree age were significantly different before and after the age of 49 years (Table 2); although the diameter increment at 1.13 m was large from the time when the main trunk reached that height, it did not change after the main trunk was broken, and varied between 0.5 and 0.7 cm·year⁻¹ during the first 40 years (Fig. 3). Around the age of 85 years when the cross-sectional area increment at 0.15 m dropped (Fig. 2), the height increment of shoot 2 increased, and shoots 1 and 3 started to grow (Fig. 4). Statistical tests showed the average height increments of shoot 2 were significantly different before and after the age of 88 years (Table 2). In 1978 when hardwood trees were harvested and sugi seedlings were planted, at the age of 111 years, the height increment of shoot 3 increased (Fig. 4), and statistical tests showed the average height increments of shoot 4 were significantly different before and after the age of 112 years (Table 2). Moreover, the cross-sectional area increment at 0.15 m increased again, and this was followed by an increase in the cross-sectional area increment at 1.13 m (Fig. 2).

Budding and Growth of Pollard Shoots

Seven shoots were found based on the external form (Table 1). However, an additional shoot was identified when examining the photographs of disks D2, D3, and D4 (Fig. 5). This shoot was

| No. | Reference (m) | Height from the reference to the tip (m) | Total height (m) | Height from the reference to the bottom of crown (m) | Height to the bottom of crown (m) | Note |
|-----|---------------|----------------------------------------|-----------------|-------------------------------------------------------|-------------------------------|------|
| 1   | M1            | 2.46                                   | 20.16           | 22.62                                                 | 2.66                          | 5.12 | Dead, between 1 and 2 |
| 2   |               | 2.46                                   | 22.68           | 25.14                                                 | 4.55                          | 7.01 | Extend outward Dead, between 4 and main trunk |
| 3   | M2            | 1.96                                   | 9.67            | 11.63                                                 | 1.66                          | 3.62 | Extend outward Dead, between 4 and main trunk |
| 4   | M3            | 2.40                                   | 7.92            | 10.32                                                 | 2.44                          | 4.84 | Extend outward Dead, between 4 and main trunk |
merged with shoot 1 (Table 3), so there had been a total of eight shoots, excluding small ones, which survived for some time. The three dead shoots budded on the remaining trunk between 1.13 m and 1.43 m, live shoots 3 and 4 budded on the remaining trunk at 1.43 m and 1.53 m, respectively, and live shoots 1 and 2 budded between 1.83 m and 2.03 m (Table 3). That is, the more dominant shoots appeared at higher position on the remaining trunk. Moreover, decay was found around the dead shoots (Fig. 5 and Table 3).

### DISCUSSION

In this study, we carried out stem analysis on a pollarded tree. The part of a coppiced tree that differs most from a single-stemmed tree is the connecting area between the remaining trunk and the pollard shoots. The distribution of annual rings in this part varied greatly. In this study, we took pictures of six surfaces of three disks taken from this part of the tree (Fig. 5). This is an effective way to determine the budding location and timing of appearance of the pollard shoots based on the distribution of annual rings.

Furthermore, the year when the main trunk was broken and its height and diameter outside the bark at 1.13 m in that year were estimated. We can be fairly certain about the year and the diameter because they were mainly based on the number and width of annual rings on disks. In contrast, the estimated height has high uncertainty. This is because its estimation makes use of the height growth at the juvenile stage, which is very slow, although annual rings of the main trunk could not be counted on.
the two disk side, in addition to the number and width of annual rings. Nevertheless, the estimated height was consistently greater than 2.46 m, which was the highest shoot reference height.

The stem analysis showed that the cross-sectional growth and diameter growth visible in the disk taken at 0.15 m increased rapidly several years after the main trunk was broken (Figs. 2 and 3). This is consistent with Suzuki’s (2019) observation of a disk from a remaining trunk of a pollarded wild sawara cypress tree. On the other hand, the diameter growth visible in the disk from 1.13 m was almost constant (Fig. 2), although the cross-sectional growth increased after the main trunk was broken (Fig. 3). Sawata et al. (2007) showed that the diameter growth of wild sugi trees varied between 0.24 and 0.52 cm year⁻¹ and inferred that their growth increased after dominant trees in the stands were cut, thus releasing these understory trees. For the tree in this study, the diameter growth at 1.13 m was over 0.5 cm year⁻¹ from the beginning (Fig. 3) and the height growth of the main trunk increased rapidly before the main trunk was broken (Fig. 4). This suggests that hardwood trees were harvested before the main trunk was broken and the tree grew rapidly once it reached a height of 1.13 m.

It was confirmed that shoot M2 (now dead) was present before 1900. Thus, a short branch which existed before the main trunk was broken grew straight up. Shoot 1-5 (merged with shoot 1) and shoot 2 started to grow around 1912–1913 (Table 3). Because this was after the main trunk was broken, there are two possibilities: that they sprouted anew or that very small branches grew straight up just after the main trunk was broken. In 1978, when hardwood trees were harvested and sugi seedlings were planted, the height of shoot 3 increased (Fig. 4). In contrast, the
height of shoot 4 exhibited constant growth. This may because there were two more shoots, shoots M2 and M3 (now dead), beside shoot 4 at that time (Table 1), and the three shoots competed with each other. Shoots 1 and 3 started to grow around 1952–1953 and the height of shoot 2 increased faster from 1955. This was about 25 years before the surrounding hardwood trees were clearcut, so it is possible that, at this time, hardwood trees in the stand were also clearcut and light conditions got better for

Fig. 5. Disks in the connecting part of the tree at 1.43 m (a), 1.53 m (b), 1.73 m (c), 1.83 m (d), 2.03 m (e) and 2.13 m (f) above the ground. Disks a, c, and e were flipped horizontally so that their orientation was the same as disks b, d, and f. Disk images were clipped out of photographs using Paint 3D.
Competition between the pollard shoots was found and the one that emerged from higher up the trunk was dominant over those from lower down the trunk. The dead shoots led to decay. This implies that the shoots which grew and then died caused decay in the remaining trunk. In order to obtain a high-quality large log from a remaining trunk, it is necessary to prevent this kind of mortality of shoots. Therefore, in the pollarding system for wild sugi trees, the shoots that are most likely to die should be pruned before they grow larger.

**CONCLUSIONS**

In this study we propose a method of stem analysis for pollarded trees, and show that breaking the top part of the main trunk has a large effect on the secondary growth of the remaining trunk. The data presented here suggest that topping the main trunk also affects the secondary growth of the remaining trunk. Competition among the pollard shoots was found, suggesting that shoots which are likely to die should be pruned before they grow much, in order to obtain large, high-quality logs from remaining trunks. However, we carried out the stem analysis on only one tree. Collecting more data is necessary to confirm the results of this study.

**ACKNOWLEDGEMENTS**

This study was funded by National Land Afforestation Promotion Organization. We would like to thank Mr. Kiyoshi Tsuchiya for providing us with the study tree and Mr. Bunji Hidano, the President of Nakaso Forestry for facilitating the stem analysis. We would also like to thank two anonymous reviewers for their constructive comments on our manuscript.

**LITERATURE CITED**

Dufour, L., Gosme, M., Le Bec, J. and Dupraz, C. (2018) Impact of pollarding on growth and development of adult agroforestry walnut trees. In: Ferreiro-Dominguez, N. and Mosquera-Losada, M.R. (eds) Proceedings of the 4th European agroforestry conference – Agroforestry as sustainable land use. European Agroforestry Federation and University of Santiago de Compostela in Lugo: 493–496

Ghahramany, L., Shakeri, Z., Ghalavand, E. and Ghazanfari, H. (2017) Does diameter increment of Lebanon oak trees (*Quercus libani* Oliv.) affected by pollarding in Northern Zagros, Iran? Agroforest. Syst. 91: 741–748

Nakashizuka, T., Izaki, J., Matsui, K. and Nagaike, T. (2000) Establishment of a pollard beech forest, “Agariko”, in Mt. Chokai, northern Japan. Jpn. For. Soc. 82: 171–178 (in Japanese with English abstract)

Nakayama, H. (1957) *Rinboku zaiseki sokuteigaku* [Timber volume mensuration]. Kanehara, Tokyo, 280 pp (in Japanese)

Nihei, A. (2005) *Dendro measure*. http://nobo.world.coocan.jp/ (accessed on 23 July 2019)

Table 3 Results of stem analysis of the pollard shoots

| No. | Height of the lowest disk that annual rings were found (m) | Number of annual rings from the center to the outermost | Height of budding (m) | The earliest year when annual rings were counted | Note |
|-----|----------------------------------------------------------|--------------------------------------------------------|----------------------|-----------------------------------------------|------|
| 1   | 2.03                                                     | 68                                                     | 1.83–2.03            | 1952                                          | 85   |
| 1-2 | 2.03                                                     | 69                                                     | 1.83–2.03            | 1951                                          | 84   |
| 1-3 | 2.03                                                     | 69                                                     | 1.83–2.03            | 1951                                          | 84   |
| 1-4 | 2.03                                                     | 68                                                     | 1.83–2.03            | 1952                                          | 85   |
| 1-5 | 1.83                                                     | 108                                                    | 1.73–1.83            | 1912                                          | 45   |
| M1  | 1.43                                                     | Decay                                                  | 1.13–1.23            |                                               |      |
| 2   | 2.03                                                     | 107                                                    | 1.83–2.03            | 1913                                          | 46   |
| 3   | 1.53                                                     | 67                                                     | 1.43                 | 1953 *1                                        | 86   |
| M2  | 1.43                                                     | Decay                                                  | 1.13–1.23            | 1900 *2                                        | 33   |
| 4   | 1.53                                                     | Around 1.53                                            |                      | 1966 *3                                        | 99   |
| M3  | 1.43                                                     | Decay                                                  | 1.13–1.43            |                                               |      |

*1 The year was determined from the disk at 1.96 m above the ground in the connecting part.
*2 The year was determined from the disk at 1.53 m above the ground in the connecting part.
*3 The year was determined from the disk at 2.4 m above the ground, the reference for the pollard shoot.

Table 3 Results of stem analysis of the pollard shoots

The remaining sugi trees.

The remaining sugi trees.
Osumi, S. (ed) (1987) Shinrin keisokugaku kogi [Lecture on forest mensuration]. Yokendo, Tokyo, 287 pp (in Japanese)

Sawata, S., Nishizono, T., Awaya, Y. and Nobori, Y. (2007) Analysis of stem growth pattern in Japanese cedar (Cryptomeria japonica) trees in a natural forest in Akita, Northeastern Japan. J. Jpn. For. Soc. 89: 200–207 (in Japanese with English abstract)

Shigemoto, M. (1950) Kitayama no sugiringyo [Sugi (Cryptomeria japonica) forestry in Kitayama area]. In Sato, Y. (ed) Sugi no kenkyu [Studies on sugi (Cryptomeria japonica)]. Yokendo, Tokyo: 622–636 (in Japanese)

Suzuki, W. (2019) Agariko no seitaishi [Natural history of pollarded trees]. J-FIC, Tokyo, 151 pp (in Japanese)

Tatsuhara, S., Yamada, K., Akashi, H., Ohashi, S. and Takeuchi, K. (2017) Use of pollarded natural Cryptomeria japonica trees in Otokoro, Itoigawa City, Niigata Prefecture. Jpn. J. For. Plann. 50: 75–84 (in Japanese with English abstract)

Tatsuhara, S., Yamada, K., Akashi, H., and Takeuchi, K. (2020) Use of wild sugi (Cryptomeria japonica) trees in Mikawa area, Aga Town, Niigata Prefecture, Japan. J. Jpn. For. Soc. 102: 288–299 (in Japanese with English abstract)

Tomita, Y. and Uchiyama, T. (2004) Excel o tsukatta baionekanizumu no tame no tokeigaku (3) [Statistics for biomechanisms using Excel (3)]. J. Soc. Biomechanisms 28: 221–225 (in Japanese)

(Received 30 September 2020)
(accepted 18 March 2021)
(J-STAGE Advance Published 12 April 2021)