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Reconstruction of Resin Collection History of Pine Forests in Korea from Tree-Ring Dating

En-Bi Choi [1], Yo-Jung Kim [2], Jun-Hui Park [1], Chan-Ryul Park [3,*] and Jeong-Wook Seo [1,*]

[1] Department of Forest Product, Chungbuk National University, Cheongju 28644, Korea; chenbi0715@chungbuk.ac.kr (E.-B.C.); fairy@chungbuk.ac.kr (J.-H.P.)
[2] Department of Wood and Paper Science, Chungbuk National University, Cheongju 28644, Korea; wnsgml9547@chungbuk.ac.kr
[3] Urban Forests Research Center, National Institute of Forest Science, Seoul 02455, Korea
* Correspondence: maeulsoop@korea.kr (C.-R.P.); jwseo@chungbuk.ac.kr (J.-W.S.); Tel.: +82-2-961-2612 (C.-R.P.); +82-43-261-2543 (J.-W.S.)

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Abstract: Resin is one of the traditional non-timber forest products in the Republic of Korea. In order to investigate the chronological activity of resin collection, the wounds/cuts on red pines (*Pinus densiflora*) were dated using a tree-ring analysis technique. Additionally, the size of the trees in the resin collection years and the present conditions of the trees were investigated to verify the tree conditions and the size of wounds. Eighty-eight red pines distributed over nine sites in the Republic of Korea were selected to extract increment cores and investigate the wound size. Through the tree-ring analysis, the trees with big wounds (24.7 × 104.7 cm) made via panel hacksaw method were dated in the range 1938–1952, whereas small wounds (40.2 × 20.9 cm) made via the conventional chisel method were dated between 1956 and 1973. Moreover, the red pines thicker than 20.0 cm were the ones that were used for resin collection. Furthermore, the wounds created by the conventional chisel were healed with time, whereas the ones formed via the panel hacksaw method still required long times for healing. The large wounds had the advantage of supplying a large amount of resin, but this was temporary. On the other hand, the smaller wounds formed via the traditional chisel method could generate resin for a longer time and heal faster.

Keywords: resin collection; red pines; wounds; panel hacksaw method; conventional chisel method

1. Introduction

Resin is one of the traditional non-timber forest products (NTFPs) which represents all kinds of non-timber resources produced in forests [1] in the Republic of Korea as in other countries. The use of NTFPs has remained in the form of knowledge delivered from generation to generation in a local community, rendering the community as a fundamental data source of the NTFPs. In the records of traditional forest knowledge (www.koreantk.com), resin is defined as a raw material used in traditional crafts, medicine, foods, life technology, and agriculture [2]. Various uses of pine resin with honey mel can be found in the old literature "*CHISENGYORAM*" (literally means the guideline for management of livelihood, 1691) [3], "*GOSASINSEO*" (literally means the new book for deep thinking, 1771) [4], and "*NONJEONGHOIYO*" (literally means the technical book for agriculture and forestry, 1831) [5] in Korea.

Korea was under Japanese rule between 1910 and 1945, and thus, Korea was greatly influenced by Japan's socioeconomic policy during this period. Japan entered war in the late 1930s and implemented the first seven-year plan to produce synthetic oil in 1937 [6]. The seven-year plan was implemented by the Japanese government because sufficient synthetic oil was not produced by the domestic companies

to support fuel for weapons [7]. To obtain resin from red pines (*Pinus densiflora*), the panel hacksaw method, in which a cut of around 150 cm length was made, was applied. On the other hand, in the traditional method in the Republic of Korea, the so-called chisel method was used, whereby a cut was made of approx. 6 cm width and 12–21 cm length [2].

The tree-ring analysis technique, also known as dendrochronology, is a powerful tool to date annual rings in woody plants. In the dating technique, the ring-width time series patterns obtained from the same tree species under similar growing conditions are synchronized with each other. This is called cross-dating in dendrochronology [8,9]. Cross-dating has been broadly applied to date annual rings in forest trees to investigate their dead and/or wounded years [10,11] as well as use their wood in archaeological architecture [12], wood craft [13], picture frames [14], musical instruments [15], and tracing wood trade [16]. The dating results of the cuts in tree rings could provide historical information on natural events, e.g., forest fire [17,18], landslide [19], flash flood [20,21], insect damage [22], and human activities, e.g., resin or latex collections.

The primary aim of the present study was to date resin collection from red pines (*Pinus densiflora*), estimate the tree size in the years when the resin was collected, and verify the current conditions of the trees. The results would serve as a reference to understand the changes in resin collection methods by year and determine forest policy on the sustainable usage of forest resources by resin collection methods.

2. Materials and Methods

2.1. Sampling Sites and Trees

To verify records on resin collection in ancient literature and recent public reports, the National Institute of Forest Science in the Republic of Korea conducted a survey for two years (2017–2018) on the distribution and growth conditions of red pine trees (*Pinus densiflora*) which were wounded for collecting resin. The survey revealed that the wounded pines were distributed in 43 regions in the Republic of Korea [2].

In the present work, 9 study sites were selected based on their geographical distribution (Figure 1). Except Anmyeondo (AM) and Haeinsa (HI), only one site was selected in each province. In AM and HI, we selected 2 and 3 sites, respectively, due to the presence of a large number of wounded trees there. All sites were located either in a village or close to a temple, public park, or recreation forest, where there was easy accessibility (Table 1).

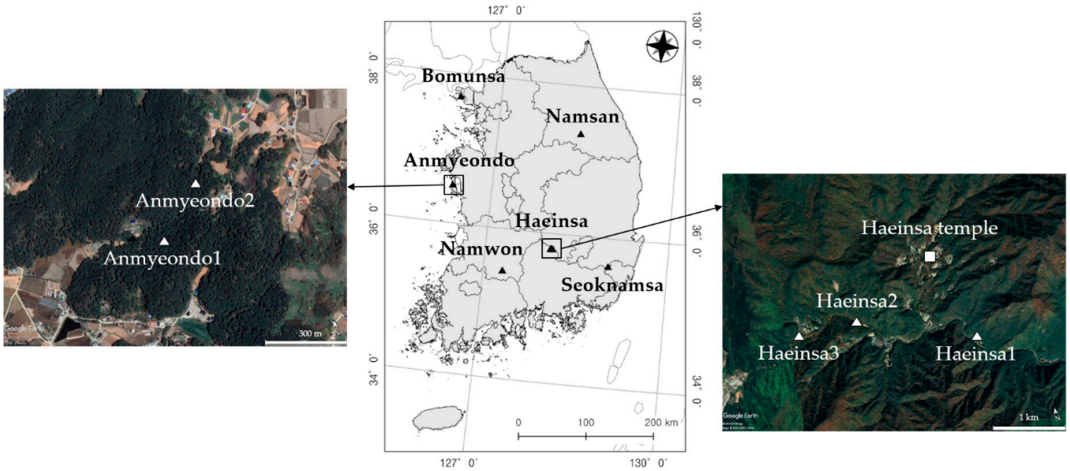


Figure 1. The locations of the sampling sites (triangles).

Table 1. Description of the sampling sites and trees (*Pinus densiflora*).

Sites	ID	Geography and Environment			Sample Trees		
		Latitude	Longitude	Elevation (m a.s.l)	Diameter(cm)		No. (n)
Bomunsa	BM	37°41′ N	126°19′ E	67–88	46.9	(±4.2)	10
Namsan	NS	37°21′ N	128°23′ E	318–334	50.7	(±4.6)	10
Anmyeondo	AM1	36°30′ N	126°21′ E	13–35	61.6	(±6.3)	10
	AM2	36°30′ N	126°21′ E	39–53	52.8	(±6.0)	10
Haeinsa	HI1	35°47′ N	128°06′ E	486–500	62.3	(±8.9)	10
	HI2	35°47′ N	128°05′ E	591–603	50.5	(±8.0)	10
	HI3	35°47′ N	128°04′ E	691–726	51.3	(±5.3)	10
Seoknamsa	SN	35°37′ N	129°02′ E	279–309	62.5	(±11.2)	10
Namwon	NW	35°26′ N	127°19′ E	145–154	60.2	(±13.4)	8

To examine the dating of resin collection and measure the wound size, 10 trees were studied at each site, except Namwon (NW), where 8 trees were used (Table 1). Mean diameters larger than 60 cm were obtained in 4 sites (AM1, HI1, SN, and NW), between 50 and 60 cm in 4 sites (NS, AM2, HI2, and HI3), and smaller than 50 cm in only one site (BM). The diameters were the means of the diameters from approximately 10 cm above and below the wounds.

2.2. Measuring the Wound Size and Collecting Increment Cores

The maximum height and width of a wound measured was reported as the size of the wound made in red pines (*Pinus densiflora*) for resin collection (Figure 2A). To establish the ring-width time series for a wounded surface, an increment core was extracted from the outermost surface of a wound (core A in Figure 2B). Likewise, to establish a reference time series to date the ring-width time series of core A, an increment core was also extracted from the opposite side, which contained tree rings continually from the current year to the year when growth started (core B in Figure 2B).

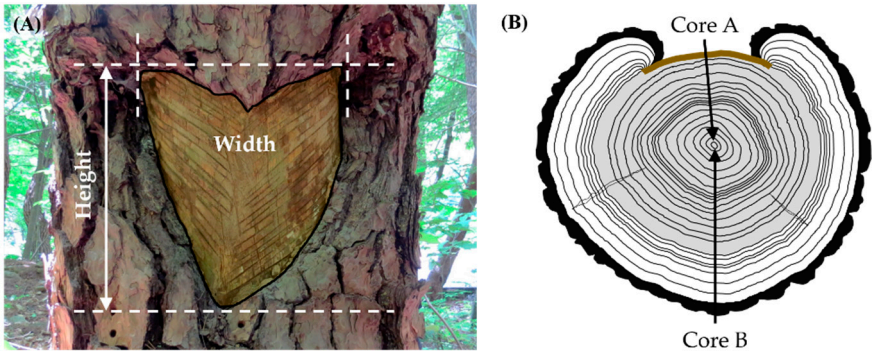


Figure 2. (**A**) Measuring the size of the wound for resin collection and (**B**) extraction of the increment core from a wounded surface (core A) and a sound surface (core B).

2.3. Sample Prepartion and Ring-Width Measurement

Before mounting, the collected increment cores were dried in air to avoid their shrinkage in the mount. When the dried cores were mounted on wooden sticks, the direction of the tracheids was kept vertical. The cross plans of the mounted cores were sanded using a belt sander unless the ring boundaries were clearly visible. The sanding was started with #80 through #120 and #360 up to #600. The ring boundaries were observed under a stereo microscope (Nikon SMZ, Japan), and the annual ring width was measured to the nearest 0.01 mm using the LINTAB (Rinntech, Germany) measurement system.

2.4. Cross-Dating

Cross-dating is a technique used to date tree rings [23] by testing the synchronization between the individual ring-width time series. In order to verify the synchronization using statistical models, *t*-value [24] and G-value [25] in the TSAP-Win program (Rinntch, Germany) were applied. The *t*-value (Equation (1)) was developed based on the number of overlapped years between the individual ring-width time series and their correlation coefficient, while the G-value (Equation (2)) was based on the year-to-year agreement between them.

$$t = \frac{r \times \sqrt{n-2}}{\sqrt{(1-r^2)}} \tag{1}$$

where r is the correlation coefficient between the individual ring-width time series and n is the number of overlapped years.

$$G_{(x,y)} = \frac{1}{n-1} \sum_{i=1}^{n-1} \left[G_{ix} + G_{iy} \right] \tag{2}$$

If $(x_{i+1} - x_i) > 0$, $G_{ix} = +1/2$, $(y_{i+1} - y_i) > 0$, $G_{iy} = +1/2$,
$(x_{i+1} - x_i) = 0$, $G_{ix} = 0$, $(y_{i+1} - y_i) = 0$, $G_{iy} = 0$,
$(x_{i+1} - x_i) < 0$, $G_{ix} = -1/2$, $(y_{i+1} - y_i) < 0$, $G_{iy} = -1/2$

where $G_{(x,y)}$ is the G-value and x_i and y_i are the measurement ring-width values for the i^{th} year.

The cross-dating was considered successful when the *t*- and/or G-values were higher than 3.5 and 65%, respectively; however, the final decision was made by synchronization between the time series through human eyes.

The local master chronologies to date the resin collection were developed using the increment cores from the opposite sides of the resin collection. The year of resin collection was assigned based on the *t*- and G-values between the individual ring-width time series and the corresponding local master chronologies.

2.5. Resin Collection Season

To determine the resin collection season, the phases of cell development in the outmost tree rings were observed under stereoscopic microscope. In the Republic of Korea, red pines growing at low altitude begin to form the annual ring in March and end between October and November [26,27]. In the temperate zone, the latewood formation in conifer trees begins in June/July [28]. Based on the past reports, the resin collection season was determined as follows: for those where only earlywood was observed in the outermost tree rings (Figure 3A), the resin collection was done between spring and early summer; for those where incomplete latewood formation was observed (Figure 3B), between late summer and autumn; and for those where complete latewood formation was observed (Figure 3C), between autumn of the current year and spring of the next year.



Figure 3. Stereoscopic observation of the outermost annual ring. (**A**) Earlywood (EW); (**B**) uncompleted latewood (UCLW); (**C**) completed latewood (CLW); PTR: previous annual ring.

2.6. Diameter of the Red Pines up to the Resin Collection Year

The diameter of the red pines during resin collection years was estimated using the increment cores extracted from the wounded side and the opposite side. The former cores were used to measure the half diameter from the pith to the wounded surface (a or a′ in Figure 4B) and the latter ones were from the pith to the tree rings formed up to the resin collection year (b or b′ in Figure 4). When the cores from the wounded side and/or the other side had pith, the half diameter up to the resin collection year was measured using the lengths of a and/or b. By contrast, when both or one core had no pith, the half diameter was measured as a′ and/or b′. The pith location to obtain a′ and b′ was estimated based on the arc of the innermost tree ring (dark black arc in B of Figure 4). The current-year thickness of the bark was applied to the bark thickness at the resin collection year. Therefore, the diameter up to the resin collection year was estimated using Equation (3).

$$D\ (cm) = a\ + b\ + 2c \text{ or } D\ (cm) = a' + b' + 2c \tag{3}$$

where D is the diameter at the resin collection year, a or a' is the observed or estimated length from the pith to the outermost tree ring of the wounded side, b or b' is the observed or estimated length from the pith to the tree ring formed at the resin collection year at the opposite side of the wound, and c is the bark thickness at the current year.

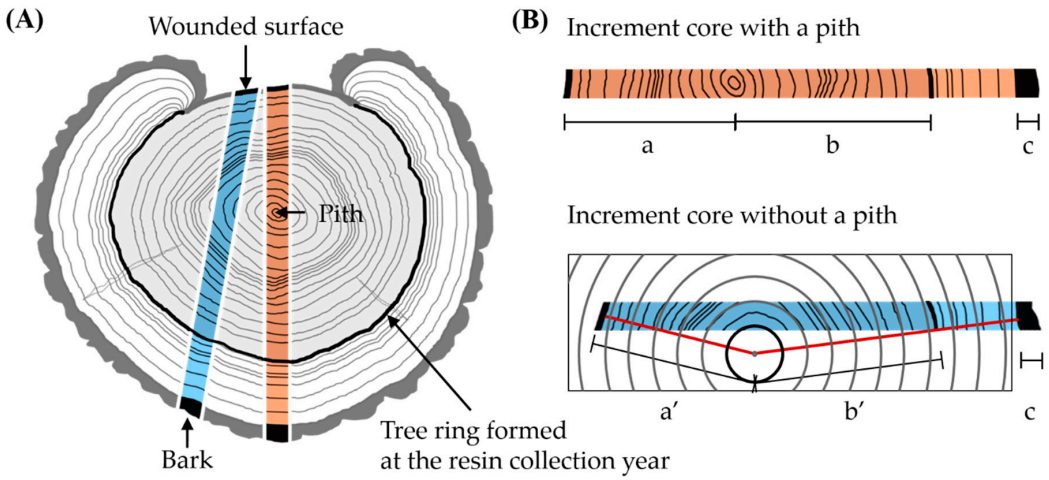


Figure 4. Illustration to estimate the diameter of red pines (*Pinus densiflora*) from the wounds of resin collection. (**A**) Cross-section with directions to extract increment cores; (**B**) estimation of the diameter at resin collection year for cores with or without pith.

The estimated dimeter (D in Figure 4), which lay extremely outside the overall distribution, had been removed from further analysis since an outlier can overestimate or underestimate the result. An outlier is determined as follows.

$$Outlier < \ Q_1 - 1.5 \times (Q_3 - Q_1)\ or > \ Q_3 + 1.5 \times (Q_3 - Q_1) \tag{4}$$

where Q_1 is the first quartile diameter and Q_3 is the third quartile diameter.

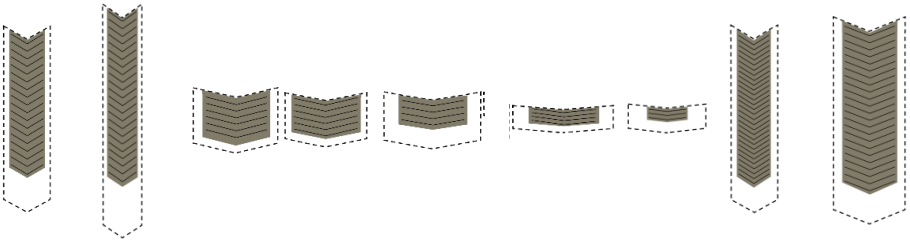
3. Results

3.1. Size of the Wounds

The wound size was categorized into two groups. Group 1, wounded by the panel hacksaw method (G1), had wounds higher and narrower than 90 and 40 cm in height and width, respectively, whereas Group 2, wounded by the traditional chisel method (G2), comprised wounds which were

lower and wider than 90 and 40 cm in length and width, respectively (Table 2). Although HI3 had wounds narrower than 40 cm in width, it was categorized into G2 based on the height, which was the lowest height among all sites.

Table 2. The mean height and width with standard deviations, the mean areas (brown color) with standard deviations (dotted line), calculated from the height and width (unit: cm).

Sites		BM	NS	AM1	AM2	HI1	HI2	HI3	SN	NW
Group		G1	G1	G2	G 2	G 2	G 2	G 2	G 1	G 1
Wounds	Height	94.0 ±24.0	113.4 ±35.2	32.1 ±9.5	28.5 ±6.3	22.1 ±14.4	12.1 ±5.2	9.8 ±8.4	100.6 ±18.5	110.6 ±21.1
	Width	22.6 ±6.9	19.5 ±5.3	42.8 ±10.8	44.1 ±7.5	43.6 ±17.3	44.8 ±18.6	25.7 ±23.4	21.5 ±8.1	35.0 ±10.4
	Areas									

BM: Bomunsa, NS: Namsan, SN: Seoknamsa, HI: Haeinsa, NW: Namwon, AM: Anmyeondo.

The mean height and width of G1 were 104.7 ± 9.0 cm and 24.7 ± 7.0 cm, respectively, whereas the mean height and width of G2 were 20.9 ± 9.8 cm and 40.2 ± 8.1 cm, respectively. Therefore, G1 had approximately 5 times higher wound height than G2, whereas G2 had approximately 1.6 times wider width than G1. The largest wound area calculated by the highest and widest values at each wound was obtained for NW, followed by NS, SN, BM, AM1, AM2, HI1, HI2, and HI3.

3.2. Dating the Resin Collection from the Trees

Based on the *t*- and G-values between the individual ring-width time series and the corresponding local master chronologies, each annual ring was given an exact calendar year (Table 3). Through the statistical tests and synchronization test between the ring-width time series from the wounds and the opposite sides and/or the corresponding local master chronologies (Table 3 and Figure 5), the years of resin collection were successfully dated for 83 red pines out of a total 88 trees (Table 4). Among the successfully dated trees, five trees in NS were dated by comparing their ring-width time series with the local master chronology because their time series were not enough long for *t*- and G-tests. Finally, from the wood cell development phases from the wounds to the outermost annual ring, the resin collection seasons were successfully determined (Table 4).

Table 3. Statistical analysis of individual ring-width time series and the corresponding local master chronology ($p < 0.05$).

Sites	T-Value			G-Value		
	Mean	Max	Min	Mean	Max	Min
BM	8.4	12.3	6.0	63.6	70.0	58.0
NS	6.5	7.6	5.3	60.5	62.0	59.0
AM1	14.2	20.6	10.3	77.9	87.0	70.0
AM2	11.4	15.9	4.8	81.9	88.0	78.0
HI1	11.4	20.5	4.4	74.7	78.0	68.0
HI2	15.8	18.5	10.3	73.9	80.0	60.0
HI3	10.9	17.7	6.1	75.3	87.0	66.0
SN	3.8	5.5	2.6	68.5	79.0	62.0
NW	5.7	13.6	3.1	70.9	78.0	65.0

BM: Bomunsa, NS: Namsan, SN: Seoknamsa, HI: Haeinsa, NW: Namwon, AM: Anmyeondo.

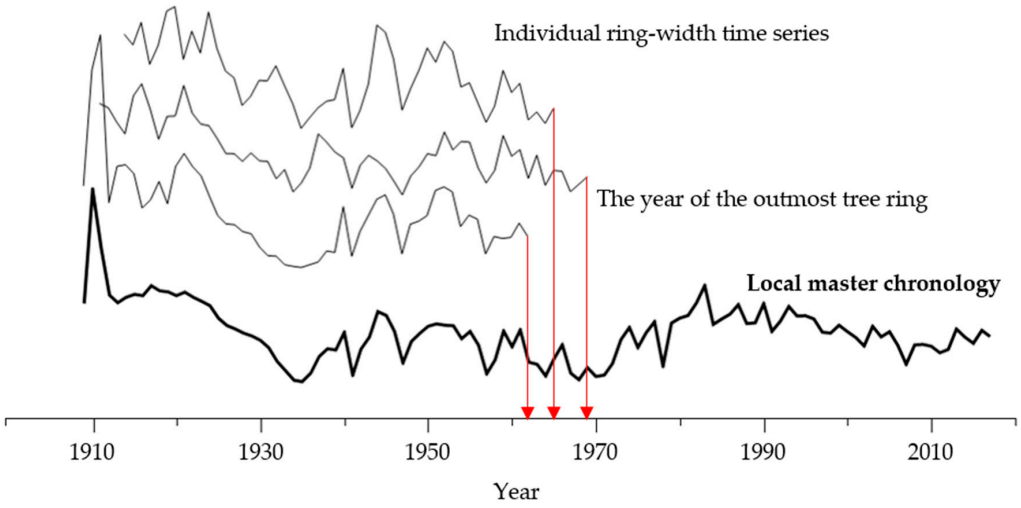


Figure 5. An example of synchronizations between individual ring-width times series from the wound surfaces and the local master chronology (AM1).

Table 4. The dated years and seasons for resin collection.

Sites	Resin Collection Periods				Dated Trees (n)
	Beginning		End		
BM	1944	Spring–Early summer	1952	Fall–Next spring	9
NS	1941	Spring–Early summer	1944	Fall–Next spring	7
AM1	1962	Spring–Early summer	1972	Fall–Next spring	10
AM2	1964	Late summer–Fall	1973	Late summer–Fall	10
HI1	1940	Spring–Early summer	1944	Late summer–Fall	10
HI2	1956	Spring–Early summer	1961	Late summer–Fall	10
HI3	1958	Spring–Early summer	1965	Late summer–Fall	10
SN	1941	Spring–Early summer	1945	Fall–Next spring	10
NW	1938	Fall–Next spring	1942	Fall–Next spring	7

BM: Bomunsa, NS: Namsan, SN: Seoknamsa, HI: Haeinsa, NW: Namwon, AM: Anmyeondo.

All the sites in G1 and HI1 in G2 showed that the resin collection occurred between autumn 1938 and autumn 1944, i.e., almost at the end of the Japanese colonial period (1910–1945). The resin collection in the other sites in G2, except HI1, was between spring 1956 and late summer 1964, i.e., after the Korean War (1950–1953) (Figure 6). Usually, the resin collection in G1 was longer than that in G2, namely in G1 for 5.6 (±1.9) years and in G2 for 8.8 (±2.2) years.

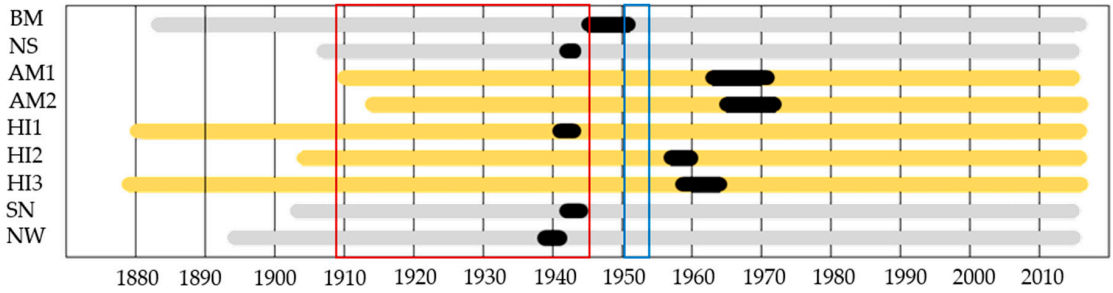


Figure 6. The length of local master chronologies (: G1, : G2) in different resin collection years (: resin collection periods). : the Japanese colonial period, : the Korean War, BM: Bomunsa, NS: Namsan, SN: Seoknamsa, HI: Haeinsa, NW: Namwon, AM: Anmyeondo.

Anatomical investigation revealed that 53.0% red pines (44 out of 83 trees) were subjected to resin collection between spring and early summer, 24.1% (20 trees) between late summer and autumn, and 22.9% (19 trees) between autumn of the current year and spring of the next year.

3.3. Diameter of the Red Pines at Resin Collection

The largest diameter (36.0 cm) at the resin collection year was recorded for NW, followed by HI1 (34.6 cm), AM1 (33.6 cm), HI2 (30.5 cm), SN (29.4 cm), AM2 (28.9 cm), BM (28.1 cm), HI3 (26.0 cm), and NS (25.0 cm) (Table 5). To avoid over- or underestimation due to the outlier, three mean diameter values, viz. AM2 (19.0 cm), SN (18.0 cm), and BM (33.7 cm), were removed from further analysis.

Table 5. Estimated diameters (cm) of the red pines at resin collection years.

Sites	Mean	Max	Min	Sites	Mean	Max	Min
BM	28.1	30.2	25.8	HI1	34.6	44.1	25.6
NS	25.0	26.9	21.9	HI2	30.5	41.7	25.6
AM1	33.6	40.1	21.5	HI3	26.0	35.3	20.5
AM2	28.9	33.4	25.4	SN	29.4	35.7	21.7
				NW	36.0	45.1	25.8

BM: Bomunsa, NS: Namsan, SN: Seoknamsa, HI: Haeinsa, NW: Namwon, AM: Anmyeondo.

4. Discussion

The results of the current study revealed that the size of the wounds for resin collection from red pines could be temporally divided into the Japanese colonial period and post Korean War period. Especially, from the end of the 1930s to the middle of the 1940s, resin collection was very intensive in the Republic of Korea to support the fuel for Japanese weapons [7]. To effectively collect a huge amount of resin, the panel hacksaw method was applied, which makes larger wounds (Figure 7A) than the traditional chisel method in Korea (Figure 7B). This information can be mainly verified from historical documents.



Figure 7. Wounds by (**A**) panel hacksaw method and (**B**) conventional chisel method.

The panel hacksaw method was mainly used between 1938 and 1945. Only BM in G1 (Table 2) showed such hacksaw wounds dated between 1944 and 1952 (Table 5). BM is located in a small island which is not well accessible from the inland. Due to BM's geographical location, the panel hacksaw method has been applied there later than other sites [2]. Unlike the G1 sites, one site in G2 (Table 2), viz. HI1, was dated between 1940 and 1944 for the resin collection. Haeinsa is one of the three Jewel Temples in the Republic of Korea, which was listed as a UNESCO World Heritage Site in

1995. Therefore, from a religious standpoint, the panel hacksaw method which makes large wounds might have not been used in Haeinsa.

The annual rings in the red pines comprised earlywood formed between spring and summer, and latewood formed between summer and autumn, similar to the conifer tree species in the northern hemisphere [26,27]. Therefore, the early- or latewood in the outermost annual ring can give seasonal information on resin collection. However, when the resin collection is determined, the wood cell development process needs to be considered. The development of the wood cells passes through the following processes: cell division in the cambium, cell expansion or elongation, cell wall thickening, cell wall sculpturing, lignification [29]. When wounds are made, the mature wood cells remain intact but the cambial cells, and the cells involved in cell expansion/elongation, cell wall thickening, and lignification, can be easily removed. These cells can be easily destroyed even by a small physical force [30]. Therefore, in most cases, the cells which are physically stable can be observed at the outermost tree ring on the wound surface. Due to this reason, the resin collection seasons can be determined one season earlier.

Most records and research on resin collection focus on the wound size and/or the technique and/or years of resin collection [2,31]. Although the diameters of red pines at the resin collection years can provide information about the forest conditions related to the trees at that time, it has not been well investigated. In the present study, the smallest and largest diameters of the red pines at each site varied from 20.5 (HI3) to 25.8 (BM and NW) cm and from 26.9 (NS) to 45.1 (NW) cm, respectively. These results indicated that the red pines thicker than 20.0 cm were used for resin collection, while trees thicker than 45.0 cm were rare.

Trees have an ability to heal wounds by forming callus tissue around the edges of the wound [32]. The duration to completely cover a wound is strongly related to the size of the wound. The current study found that some wounds created by the conventional chisel method could successfully seal the wounds (Figure 7B); however, the wounds caused by the panel hacksaw method required a long time (Figure 7A). When natural resources are obtained from trees through wounding, the wound size is considered based on the sealing ability of trees.

The panel hacksaw method is useful in increasing the collected amount of pine resin in the short term. However, it left irrevocable wounds which still exist in Korea. Unlike the panel hacksaw method, the conventional chisel method cannot produce a huge amount resin within a short period; however, it offers the advantage of sustainable collection of resin. Sustainable use of non-timber products has countless value and should be transferred to the next generation to maintain a safe and happy life.

5. Conclusions

The current study found that the panel hacksaw method was temporarily applied to collect resin intensively from pine trees under Japanese rule, and after the Korean war, the conventional chisel method was again applied to collect resin until the middle of the 1970s for livelihood. For resin collection, red pines thicker than 20.0 cm were used. The wounds created by the conventional chisel were found to be healed, whereas the ones created via the panel hacksaw method still required long times for healing. From the large wounds, a benefit is that a large amount of resin can be obtained, but these wounds take a long time to heal completely. On the other hand, the traditional chisel method offers a sustainable supply of resin and rapid healing of the wounds. Therefore, we can conclude that the traditional method to obtain non-timber forest products will be a remarkable reference to determine forest policy on the usage of forest resources sustainably and should be passed from generation to generation in Korea.

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