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Original Article

Determinate the Number of Growth Rings Using Resistograph with Tree-Ring Chronology to Investigate Ages of Big Old Trees[1]

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ABSTRACT

To verify the possibility of using resistograph to estimate the age of big old living trees, we selected three *Zelkova serrata* and seven *Pinus densiflora* in Goesan. The mean diameters at breast height of *Z. serrata* and *P. densiflora* were 102 (92-116) cm and 80 (65-110) cm, respectively. The heights measured from the ground using a resistograph ranged at 1.2-4.3 m and 0.6-1.1 m for *Z. serrata* and *P. Densiflora*, respectively. The most appropriate needle speed to determine tree-ring boundaries for measuring ring width was 1500 r/min for both tree species. Alternatively, the suitable feed speeds for *Z. serrata* and *P. densiflora* were 50 cm/min and 150 cm/min, respectively. From the measured data, the mean numbers of tree rings of *Z. serrata* and *P. densiflora* were 57 (43-68) and 104 (93-124), respectively, and the mean tree-ring widths were 4.27 mm (3.18-5.09 mm) and 2.93 mm (2.32-3.34 mm), respectively. A comparison between the time series of tree-ring widths by resistograph and that from the local master chronologies tallied for the heartwood part. Finally, this study showed that resistograph can be used to estimate tree ages when a local master chronology is available.

Keywords: tree age, Resistograph, electric resistance values, feed and needle speed, tree-ring, conifer trees, deciduous tree

1. INTRODUCTION

Since ancient times till now, the people of many villages in South Korea offer sacrifices to big old trees, usually located at village entrances for the peace of their villages (Heo *et al.*, 2011). The places, where the big old trees are, have also been used as public spaces where all the villagers gather to perform various local events (Ahn & Choi, 2001; Jeong & Yoon, 2014; Jung & Kim, 2017). Therefore, big old trees have historical and cultural values. Based on these cultural values of big old trees, national and local governments established the Forest Protection Act (Article 13, designation and management of the law-protected trees) or an Ordinance to designate and manage the trees as a natural monument or law-protected trees.

Tree age is one of the important parameters to evaluate the historical and cultural values of big old

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trees. For this reason, we tried to estimate the age as accurately as possible. There are three representative methods to investigate a tree's age, viz. tree rings, nodes, and diameter (Son *et al*., 2007). The most accurate method of these three is to count the number of tree rings(Jeong *et al*., 2017; Seo *et al*., 2017a, b). Especially, the number of tree rings at the boundary between the root and stem represents the tree age (Part *et al*., 1987). However, it is almost impossible to investigate tree rings at the boundary without cutting the tree. Therefore, the tree age is normally investigated using increment cores extracted at breast height of the stem, and in order to estimate more precisely, the estimated year is added to the height growth from the ground up to the breast level (Wong & Lertzman, 2001).

Now, during sampling using an increment borer, wounding the stem cannot be avoided. Although this wounding does not impart a great effect on the tree growth and/or the life of the tree, we are reluctant to use an increment borer for sampling. Resistograph is an equipment designed to measure the degree of wood decay, cavities, and crack (Frank, 1994, 2013; Gruber, 2000). The operation of a resistograph is based on electrical resistance It comprises an electronically controlled drill resistance which has a strong linear relationship with wood density (Frank, 2012). Conifer and ring porous trees in temperate zone show the lowest and highest densities in the early- and latewood within the tree rings, respectively (Schweingruber, 1988). Using the pattern of density variations measured by resistograph, we can investigate tree ages (Bilgin *et al*., 2012; Lukaszkiewicz *et al*., 2005). The greatest advantage of a resistograph in counting and/or measuring tree rings is that it makes smaller wounds (Ø 2 mm) than the ones by an increment borer (Ø more than 5 mm). In previous study, it was verified that resistograph can most perfectly measure tree-ring widths larger than 1 mm (Oh *et al.,* 2019).

Decay within trees is one of difficulties in investigating tree ages. Most big old trees are partially decayed and the decayed locations are variously distributed within the stems. Due to such conditions, it is difficult to obtain continuous tree rings from the bark to the pith, and therefore, it is a challenge to measure the innermost tree ring, which is the most important reference in determining the tree age. In dendrochronology, dating is done by comparing an undated tree-ring time series with a dated long tree-ring time series (master chronology), which is called 'cross-dating' (Schweingruber, 1988). This method can be used to identify the logging year of the timber, to date wooden artifacts excavated at the site(Lee *et al*., 2018), and to track the origin of the timber(Eckstein and Wrobel, 2007). If we have longer than around 50-year time series with the inner most tree ring, the inner most tree ring can be dated by the cross-dating method. Oh *et al*. (2017) established the master chronology of *Pinus densiflora* and *Zelkova serrata* for the provinces of Goesan in Chungbuk, Gurae in Jeonna, and Uljin in Gyeongbuk in a previous report.

The current study explored the possibility of applying resistograph to establish the tree-ring time series of big old living trees (*Pinus densiflora* and *Zelkova serrata*) in Goesan based on the results of Oh *et al*. (2019), and then, to date the tree rings by comparing the time series with the master chronology established by Oh *et al*. (2017). We believe that the results of our study could be used as a practical reference in estimating the tree age using resistograph.

2. MATERIALS and METHODS

2.1. Materials

For the present study, ten big old trees from Goesan-gun in Chungbuk were selected of which 3 were *Zelkova serrata* and 7 were *Pinus densiflora*. These tree species occupy 52% (7,302 trees) and 13% (1,753 trees) of all the protected trees, respectively (Korea Forest

Table 1. Description of the study sites and analyzed trees

Tree	Site	ID	Diameter (cm)	Measurement height from the ground (m)
Zelkova serrata	Cheongcheon-ri	CBGSZS12	92	4.3
		CBGSZS13	116	1.2
		CBGSZS14	98	1.4
Pinus densiflora	Jujin-ri	CBGSPD04	66	0.6
		CBGSPD05	70	1.0
		CBGSPD06	65	0.7
		CBGSPD07	102	1.0
		CBGSPD08	110	1.0
		CBGSPD09	65	1.0
		CBGSPD10	79	1.1

Service, 2018). The mean diameters at breast height (DBH) of *Zelkova serrata* and *Pinus densiflora* are 102 (92-116) cm and 80 (65-110) cm, respectively (Table 1). The measurement heights from the ground using resistograph were between 1.2 and 4.3 m for *Zelkova serrata,* and between 0.6 and 1.1 m for *Pinus densiflora.*

2.2. Methods

2.2.1. Ring width measurement by resistograph

Resistograph (IML-RESI PD400, Germany) was used to measure the tree-ring widths. By IML Australia ⓒ (2013), tree-ring boundaries can be clearly distinguished at electrical resistance range of 40-60% of the resistograph. In a previous study (Oh *et al*., 2019), it was suggested that the needle and feed speeds of resistograph should be decided by performing a pre-test field work. The measurement depth of the resistograph was 40 cm, which was actually the length of the needle (Fig. 1).

With respect to the current amplitudes of the resistograph from the bark to the pith in the stem of *Zelkova serrata*, the lowest part of the wave was considered as the tree-ring boundaries (Fig. 2), since the porous rings have the lowest wood density at the

Fig. 1. Measurement of electrical resistance from the bark to the pith in a stem using resistograph.

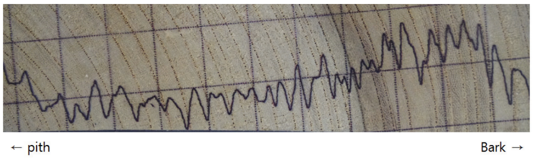

Fig. 2. Resistograph profile of *Zelkova serrata* and its tree rings (feed speed 75 cm/min).

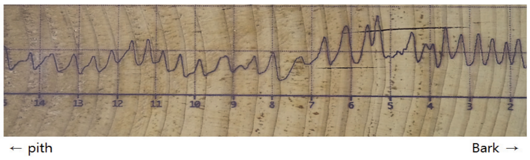

Fig. 3. Resistograph profile of *Pinus densiflora* and its tree rings (feed speed 150 cm/min).

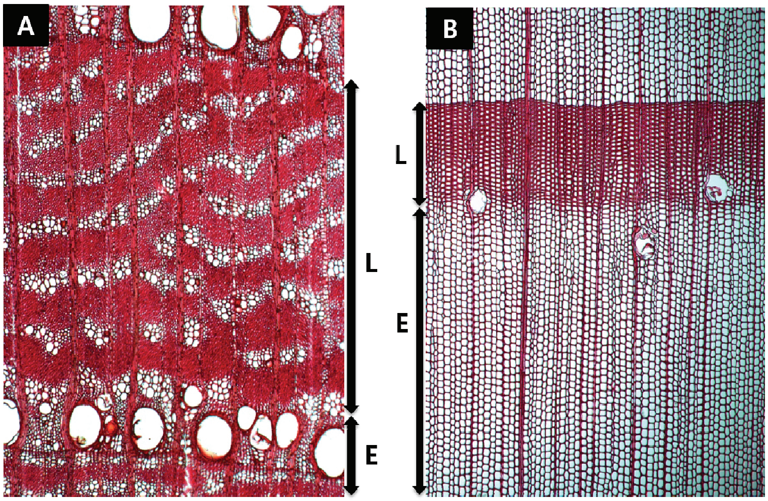

Fig. 4. Cross-sections of (A) *Zelkova serrata* and (B) *Pinus densiflora* (L: latewood, E: earlywood).

beginning of the tree rings where large pores were formed (Fig. 4A). Although the ring boundaries will somehow shift to the locations of the large pores in the next year, no calibration is necessary because such shifts occurred uniformly in all the tree rings. On the other hand, the tree-ring boundaries of *Pinus densiflora* were determined at the end of tree rings having the highest wood density and where latewood cells with small diameters and thick cell walls in the radial direction are present (Fig. 3). In this case, the boundaries were slightly shifted to the latewood in the current year due to same locations of the cells with the highest density within the tree rings (Fig. 4B) (Schweingruber, 1988). Similar to *Zelkova serrata*, the shifting effects did not require any calibration because such shifting were present in all the tree rings.

2.2.2 Comparison of the ring-width time series by resistograph with the local master chronologies

The ring-width time series established by electrical resistance measurement of resistography (PD-tool pro) were compared with the local master chronologies of *Zelkova serrata* and *Pinus densiflora*, established by Oh *et al.* (2017), to develop a time series using tree rings near the pith.

3. RESULTS and DISCUSSION

3.1. Feed and needle speeds

The most proper needle speed to determine tree-ring boundaries for the ring-width measurement was verified as 1500 r/min for both the tree species (Fig. 5). Whereas, the suitable feed speeds for *Zelkova serrata* and *Pinus densiflora* were 50 cm/min and 150 cm/min, respectively.

In the previous study (Oh *et al.,* 2017), it was suggested that the most suitable needle speed to determine tree-ring boundaries in the measurement data was 1500 r/min for all the experimental tree species (*Pinus koraiensis*, *Larix kaempferi*, *Pseudotsuga menziesii*, *Abies holophylla* and *Zelkova serrata*), which was done using disks. In the current study, although

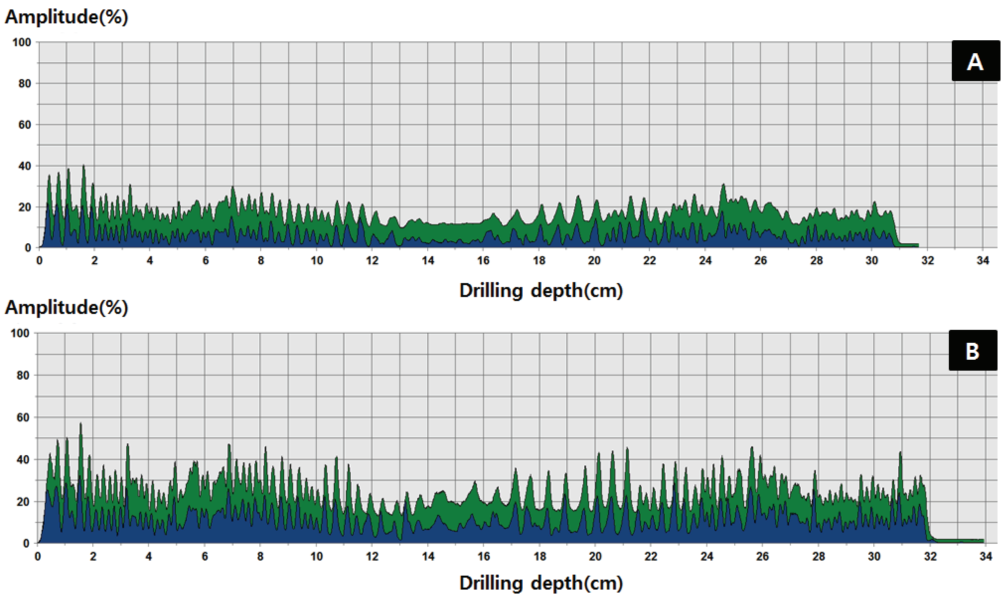

Fig. 5. Graphs of needle speeds of 2500 r/min (A) and 1500 r/min (B) for *Pinus densiflora*.

resistograph was applied, the most suitable needle speed was also verified to be 1500 r/min. Based on these results, the needle speed of 1500 r/min might be the most proper option for measurement of tree-ring widths in general.

The feed speeds should be set differently depending on the density difference of the species(Frank, 1994). The feed speeds to determine tree-ring boundaries suggested by Oh *et al.* (2017) were different depending upon the tree species. The most suitable feed speed for *Larix kaempferi* and *Pseudotsuga menziesii* was 100 cm/min, for *Pinus koraiensis* 175 cm/min, for *Abies holophylla* 150 cm/min, and for *Zelkova serrata* 75 cm/min. In our study, however, the most suitable feed speed for *Zelkova serrata* was found to be 50 cm/min, different from the past report (Oh *et al.*, 2017). Although there is no reference for *Pinus densiflora*, the proper feed speed for this tree was same as that of *Abies holophylla,* i.e. 150 cm/min. The differences of feed speeds between living trees and wood is due to different moisture content in the stems and disks (Bilgin *et al.,* 2012).

3.2. Tree–ring time series established by resistograph

As illustrated in Fig. 6 and 7, three tree-ring time series of 3 big old *Zelkova serrata* and 7 big old *Pinus densiflra* were established. The mean number of tree rings of *Zelkova serrata* and *Pinus densiflora* were 57 (43–68) and 104 (93-124) and the mean tree-ring widths were 4.27 mm (3.18-5.09 mm) and 2.93 mm (2.32-3.34 mm), respectively (Table 2 & 3).

According to Oh *et al.* (2019), resistograph fails to measure tree-ring boundaries which are narrower than 1 mm. Therefore, the results showed differences between the number of tree rings observed in disks and those counted from the measurement data. Similarly, in the current study, the tree rings which are narrower than 1 mm will also not be well detected if the resistograph data are used. Therefore, the number of tree rings would be lower than the real existing tree rings. Especially, such errors would be more predominant in the sapwood due to aging effect (Schweingruber, 1988; Park 1993).

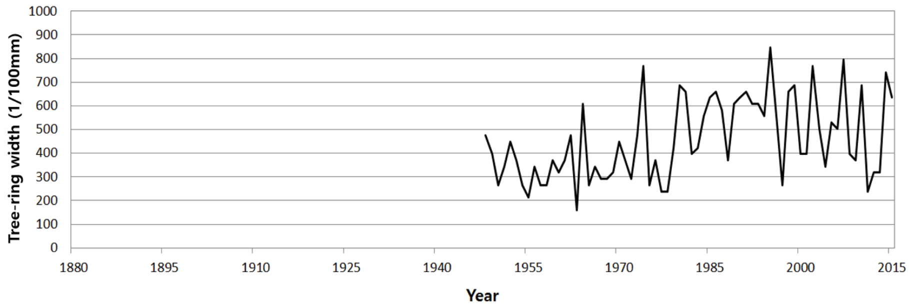

Fig. 6. Annual tree-ring time series of *Zelkova serrata* (CBGSZS12) by resistograph.

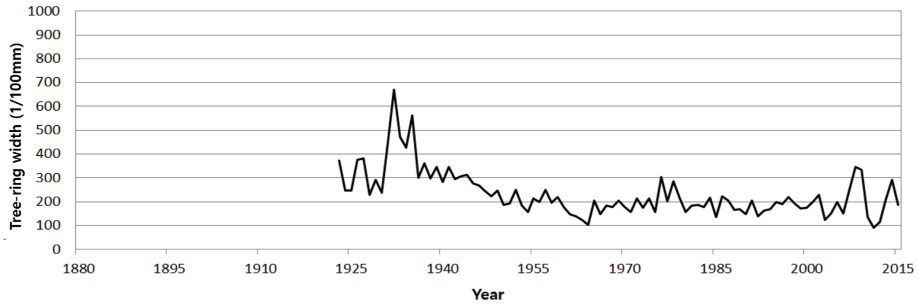

Fig. 7. Annual tree-ring time series of *Pinus densiflora* (CBGSPD04) by resistograph.

Table 2. Information on the tree-ring widths of *Zelkova serrata* by resistograph

ID	No. of measured direction	Number of tree rings	Tree-ring width (mm)		
			Minimum	Mean	Maximum
CBGSZS12	2	68	1.59	4.55	8.47
CBGSZS13	1	43	1.59	3.18	6.35
CBGSZS14	2	60	2,12	5.09	10.58

Table 3. Information on the tree-ring widths of *Pinus densiflora* by resistograph

ID	No. of measured direction	Number of tree rings	Tree-ring width (mm)		
			Minimum	Mean	Maximum
CBGSPD04	2	93	0.90	2.32	6.72
CBGSPD05	2	109	1.26	2.82	9.41
CBGSPD06	2	94	1.11	2.78	5.72
CBGSPD07	2	103	1.35	3.34	7.06
CBGSPD08	2	124	1.14	2.96	8.90
CBGSPD09	2	103	1.26	3.22	7.74
CBGSPD10	2	108	1.05	3.04	9.23

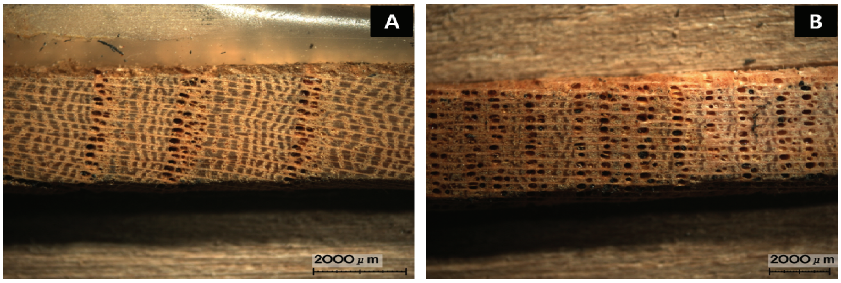

Fig. 8. Distinct tree-ring boundaries (A: heartwood) and indistinct one (B: sapwood) for *Zelkova serrata* (×10).

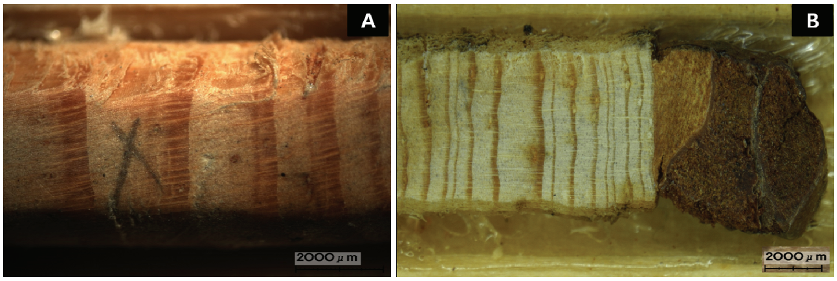

Fig. 9. Distinct tree-ring boundaries (A: heartwood) and indistinct one (B: sapwood) for *Pinus densiflora* (×10).

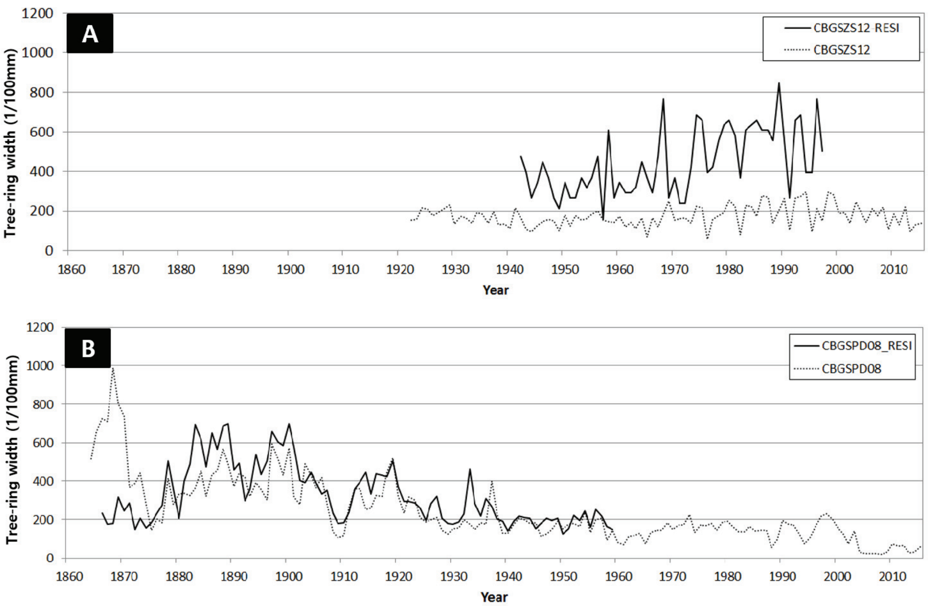

Fig. 10. Cross-dating after removing sapwood (A: CBGSZS12, B: CBGSPD08).

3.3. Comparison of tree-ring time series by resistograph with the local master chronologies

The tree rings in the sapwood are usually narrower than ones in the heartwood (Fig. 8 & 9). Therefore, the cross-dating technique was mostly applied to the tree rings in the heartwood for dating. By employing this strategy for cross-dating, the calendar year of the innermost tree rings could be successfully dated (Fig. 10). Therefore, the present study verified that the tree-ring time series by resistograph represent the real ring-width time series in the heartwood. To use resistograph to estimate the tree ages in other provinces, master chronologies, which are responsible for various tree species and provinces, need to be established.

4. CONCLUSION

To conclude, tree-ring time series for big old trees was established and tree-ring was dated. The most suitable needle speed to establish tree-ring time series for living big old *Zekova serrata* and *Pinus densiflora* using resistograph was 1500 r/min, whereas the most suitable feed speeds were 50 cm/min for the former and 150 cm/min for the latter. Although tree rings narrower than 1 mm and/or in the sapwood could not be well detected from the electrical measurement data of resistograph, it was verified that the tree rings in heartwood can be distinguished using the measured data. Therefore, the time series by resistograph can be dated with the available master chronology using the measurement data of tree-ring widths. Based on these results, we conclude that resistograph can be applied to estimate the age of trees located where a local master chronology is available.

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