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Investigating into the Death Years of Evergreen Conifers in Landslide Areas of Jirisan National Park and the Abrupt Growth Reduction During Their Living

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ABSTRACT

The present study aimed to investigate the death years of conifers to verify the time difference between landslide occurrence in 2011 and tree mortality near Chibanmok and Jangteomok shelters in the Jirisan National Park. Furthermore, abrupt growth reduction was also investigated to verify the living conditions when they were living. For the study, tree-ring analysis was conducted by selecting 14 living *Abies koreana* near the landslide area and 7 dead ones in the landslide area in the Chibanmok site, and 13 living conifers (7 *Picea jezoensis*, 5 *A. koreana*, and 1 *Pinus koraiensis*) near landslide area and 4 dead ones (2 *P. jezoensis* and 2 *A. koreana*) in landslide area in the Jangteomok site. Using the tree-ring samples from living *A. koreana* 137-year long chronology (1885–2021) was established for the Chibanmok site and 364- and 65-year long *P. jezoensis* (1658–2021) and *A. koreana* (1957–2021) chronologies was built for the Jangteomok site. Through the synchronization test between the tree-ring time series from dead conifers and the corresponding chronologies, it was verified that the death of conifers in the landslide areas occurred after 2011, when the landslide happened, except for only one tree. It was further verified through the abrupt growth reduction test that the growth condition of dead conifers before the landslide in 2011 was satisfactory.

Keywords: dendrogeomorphology, landslide, conifer, death year, growth reduction

1. INTRODUCTION

Dendrochronology is the study of dating annual rings and using various environmental and growth-related information stored in the annual rings. There are various study areas in Dendrochronology involves several areas, such as dendroclimatology, dendroecology, dendrogeomorphology, and dendroarchaeology (Bigler and Bugmann, 2003; Choi *et al*., 2020a, 2020b; Ju *et al*., 2023; Lee *et al*., 2022; Park *et al*., 2023; Rybníček *et al*., 2020; Struble *et al*., 2020). Among these, dendrogeomorphology involves the investigation of the occurrence years of landslides, soil erosion, debris flow, and floods or the topographical changes brought about by these natural

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events (Alestalo, 1971; Bovi *et al*., 2022; Shroder, 1980). According to Shroder's diagram (Shroder, 1978), landslides cause wounds in the xylem, expose or damage the roots, and bury or tilt the stems. Moreover, the stress generated by landslides causes traumatic resin canal or callus in the tree rings, or compression or tension wood (Šilhán, 2021). Based on these anatomical characteristics, dendrogeomorphological studies are done mostly in Switzerland and Czech Republic (Šilhán, 2020; Stoffel *et al*., 2013), but not in Korea yet.

A landslide occurs when soil mass loses its balance and collapses due to gravity. The landslide is one of the major natural events that causes damage to the natural resources (Ma and Jeong, 2007; Yun *et al*., 2021). Most landslides in Korea are caused by heavy rain in summer and the number of landslides is increasing more and more due to abrupt changes in climate, such as local heavy rain (KFS, 2022). Since large or small landslides occur frequently in the National Park areas, studies of landslides are still continuing after it started in 2007 (Jeong *et al*., 2016; KNPRI, 2022; Ma and Jeong, 2007). According to a study, the damaged area in the Jirisan National Park was 143,524 m^2, which is the 2^{nd} largest damaged area after Seoraksan in Korea (KNPRI, 2022). By monitoring a wide variety of topographical parameters, namely slope gradient, aspect, vertical slope, cross slope, altitude, forest type, parent rock, soil depth, and landslide position, width, length, and area, it was verified that most landslides in the Jirisan National Park occurred at relatively lower altitudes and in conifer forests compared with the other national parks (KNPRI, 2020).

The area of the Jirisan National Park is approximately 483 km^2, the largest one in Korea (KNPRI, 2019). In particular, the subalpine conifer area is approximately 46 km^2, accounting for 9.4% of the park area, which is the second largest one in the national parks (KNPRI, 2016). Aerial images have revealed that the area of conifer species decreased from 16.1% to 13.8% over 20 years (Kim *et al*., 2019), and the population of dead *Abies koreana* increased 2–5 times (Park *et al*., 2020). In the mountain areas of southeastern Alaska, USA, it was reported that landslides increased 3.8 times due to decline in growth of yellow cedar (*Chamaecyparis nootkatensis*) in the area. Decay of tree roots, which renders the soil unstable, is considered the principal reason for landslides (Johnson and Wilcock, 2002; Preti, 2013). Based on such study, the enhanced tree mortality due to climate change was suggested as a parameter that induces landslides.

In the present study, we present the relationship between the timing of landslides and the death year of conifers in the landslide areas in the Jirisan National Park. Moreover, the growth vitality of the dead trees, when they were alive, was also investigated to improve our understanding of the mortality reason.

2. MATERIALS and METHODS

2.1. Study sites

Among thirteen landslide areas in the Jirisan National Park, two locations were selected for the study where the conifer species were dominantly distributed. The two locations are located at Chibatmok (site ID: LSJR01-01-01) and Jangteomok (site ID: LSJR02-04-02; KNPRI, 2017) where the landslide occurred in 2011 (Fig. 1). The distribution of tree species was verified using a vegetation map (KNPRI, 2016) and artificial intelligence to monitor the dead trees there (KNPRI, 2021). The topographical characteristics of the study sites are metamorphic rock in the parent rock, mountain collapse type in the landslides, and debris flow in external appearance (Table 1). The slope gradients of Chibatmok and Jangteomok were 33.1 and 32.9 degrees, respectively. The Chibatmok is the second largest landslide site of area 20,128 m^2 and the Jangteomok is the sixth of area 5,011 m^2 among the 54 landslide sites distributed in thirteen

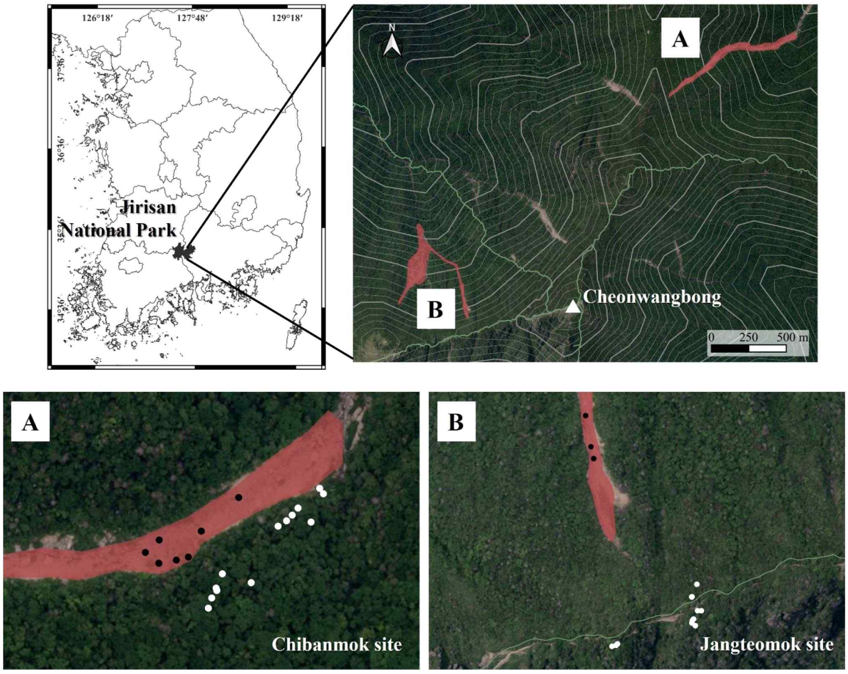

Fig. 1. Sampling sites (A) Chibanmok and (B) Jangteomok in the Jirisan National Park with landslide areas (red areas). The black dots within the landslide areas are the locations of the selected dead trees, while the white dots are the locations of the living trees used to build the site chronology.

Table 1. Description of the landslide areas

Area	Altitude (m a.s.l.)	Bedrock	Type		Soil	Slope angle	Area (m^2)
			Location	Movement			
Chibanmok	1,709.6	Metamorphic rock	Hillside	Flows	Sandy soil	33.1°	20,128
Jangteomok	1,733.7				Decomposed granite	32.9°	5,011

areas.

2.2. Sampling

The vegetation of Chibatmok is dominated by *A. koreana*. Most of the dead trees in the site were identified as *A. koreana* based on the shape and bark. To verify the differences between the occurrences of landslide and the tree death, increment cores were acquired from seven dead *A. koreana* within the landslide site. Additionally, to establish the site chronology for dating the death years, increment cores were extracted from fourteen living trees close to the site (Table 2). On the other hand, the vegetation of Jangteomok is dominated by *A. koreana* and *Picea jezoensis*. Same as above, two increment cores were extracted from each dead *A. koreana* and *P. jezoensis* within the site, and eight and five cores from living *A. koreana* and *P. jezoensis* to establish the site chronologies, respectively. Among the dead trees, only limited numbers were selected due to

Table 2. Description of the sampling sites and trees

Site	Condition	ID	No. of samples	Latitude	Longitude	Altitude (m a.s.l.)	Diameter (cm)
Chibanmok	Living	JCBKL	14	35° 20' 53–56"	127° 44' 30–34"	1,435.7	29.0
	Dead	JCBKD	7	35° 20' 54–56"	127° 44' 29–32"	1,434.1	18.1
Jangteomok	Living	JJTKL JJTJL	13	35° 20' 08–11"	127° 43' 29–33"	1,795.5	28.4
	Dead	JJTKD JJTJD	4	35° 20' 13–16"	127° 43' 28–29"	1,674.8	25.8

dangerous site condition to reach the trees and no good bark condition was found.

The dead trees selected in the landslide sties were from the fallen ones as their roots were exposed, which is a typical damaged form by landslide (Šilhán, 2021). The tree-ring samples from the dead trees were collected as disks using a chainsaw at the height of 1 m from the boundary between the stem and root, whereas, the samples from living trees were collected using an increment borer (Ø5.12 mm) at breast height from the ground; 2 increment cores from each living tree. When the increment cores from the living trees were extracted, the direction was decided along the contour direction to avoid compression of wood due to slope (Schweingruber, 1988).

2.3. Ring-width measurement and cross-dating

The increment cores were mounted on U-shaped bars so that the cells were vertically aligned, and the cross-sections were sanded using a belt sander. The entire cross-section of the disks collected from the dead trees was also sanded using a belt sander. After sanding all the samples, the annual ring boundaries were confirmed under a stereomicroscope (SMZ18, Nikon, Tokyo, Japan), while the ring widths were measured using a RINTAB (Rinntech, Heidelberg, Germany, measurement unit: 0.01 mm). To avoid errors due to measurement direction, the ring widths were measured very carefully by measuring the short distance between two adjacent ring boundaries.

In dendrochronology, cross-dating is based on the principle of limiting factors. The principle states that when the same species grow in the same environment, they share similar growth patterns due to the influence of the same limiting factors. Cross-dating refers to finding false and missing rings based on synchronization between time series graphs created with the annual ring width of each tree and assigning an accurate growth year to each annual ring. Additionally, assigning a year to a tree ring whose year of death or logging is not certain by checking the pattern of synchronization with the local master chronology for which the year is certain is also called cross-dating.

As a method to calculate pattern synchronization quantitatively, t-value [Equation (1)] and G value [Equation (2)] are used (Baillie and Pilcher, 1973; Eckstein and Bauch, 1969). In general, if the t-value and G value in dendrochronology are 3.5 and 65% or more, respectively based on a 100-year length, cross-dating done is considered statistically significant and successful; however, the final decision is made by checking synchronization with the naked eye (Kim, 2003).

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

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.

2.4. Death year and season

The death year was confirmed through cross-dating between the master chronology and individual time series of dead conifers. After determining the death year, the season of death was also derived from the wood cells observed in the outermost tree ring. The season of death was determined as spring to summer if only early-wood cells were observed in the outermost annual ring, late summer to autumn if latewood cells were observed, whereas autumn of the current year to spring of the following year if completed latewood was observed. If incompletely developed latewood cells were observed, whereas autumn of the current year to spring of the following year if completed latewood was observed (Fig. 2). When latewood cells are observed, but the outermost cell wall is not fully thickened, it is part of latewood cells. When outermost latewood cells are fully thickened and have clear boundaries, the latewood is completed and that is called a tree ring (Seo *et al*., 2021).

2.5. Analysis of growth reduction

To investigate the growth vitality, the monitoring of abrupt growth reduction technique was applied to this study. The abrupt growth reduction was determined from the annual ring width. If the annual ring width decreases by more than 40% compared to the previous year and the decrease continues for more than 3 years, it is taken as a growth reduction (Schweingruber, 1988). To confirm the intensity of growth reduction, the growth reduction was classified into three levels based on the degree of decrease in annual ring width. A decrease in annual ring width compared to the previous year was considered ‘low’ if it is 40%–55%, ‘middle’ if it is 56%–70%, and ‘extreme (high)’ if it is more than 71% (Seo *et al*., 2019).

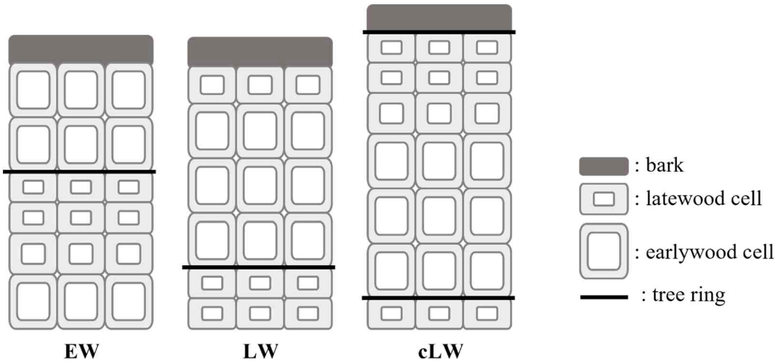

Fig. 2. Wood cell development in the outermost tree rings. EW: earlywood, LW: part of latewood, cLW: completed latewood.

3. RESULTS and DISCUSSION

3.1. Site chronologies

To date the death year of the dead trees, the site chronologies of Chibatmok and Jangteomok were built using individual ring-width time series which were cross-dated with each other. The *t*-value and G value between the individual ring-width time series and the chronology of *A. kroeana* at Chibatmok were 8.6 (2.0–14.8) and 75% (67–82), respectively. These values verified that the cross-dating was statistically successful (results not in shown). The mean *t*-values and G values of *P. jezoensis* and *A. koreana* at Jangteomok were 7.0 (0.1–12.9) and 4.0 (0.8–6.6), and 69% (60–74) and 71% (55–81), respectively. Therefore, the cross-dating at Jangteomok was also statistically successful. To visually check the success of cross-dating, the synchronization between individual tree-ring time series and the corresponding site chronologies were compared and the patterns were recognized as matching (Fig. 3). Using the cross-dated ring-width time series, 137-year (1885–2021) long chronology of *A.*

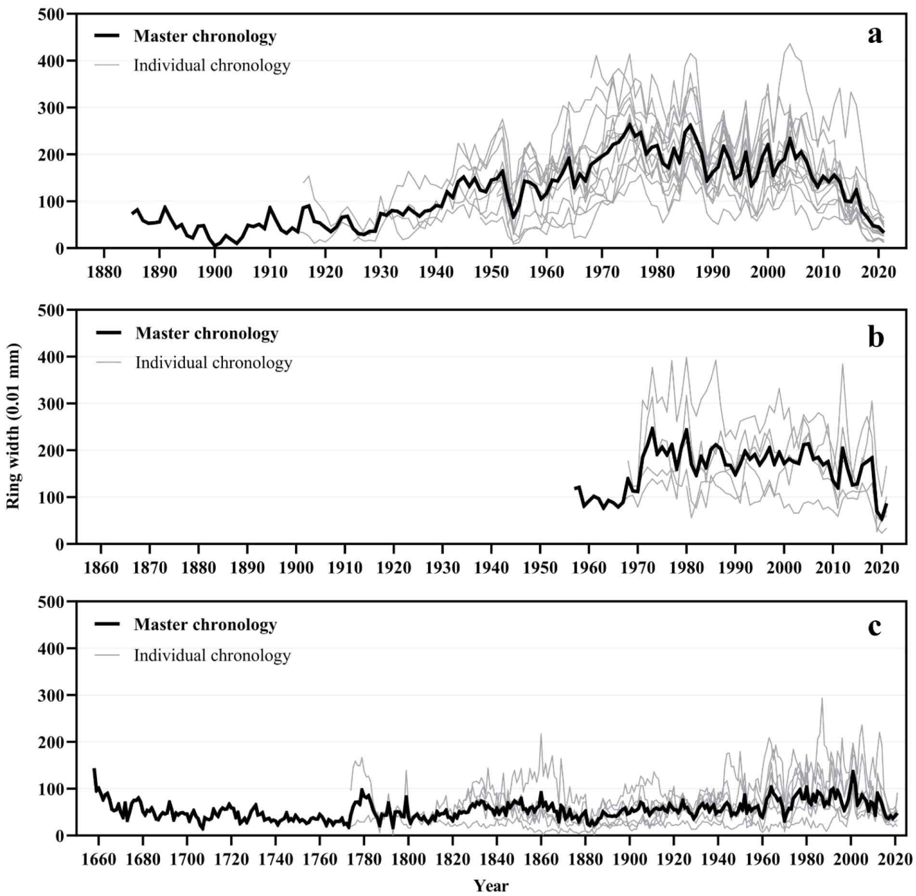

Fig. 3. Individual ring-width time series (grey line) and the master chronologies (bold black line) made by their mean values at Chibanbok [(a) *Abies koreana*] and *Jangteomok* [(b) *A. koreana*, (c) *Picea jezoensis*] site.

koreana from Chibatmok [Fig. 3(a)], and 65-year (1957–2021) long and 364-year (1658–2021) long chronologies of *A. koreana* and *P. jezoensis* from Jangteomok, respectively, were built [Fig. 3(b) and (c)].

3.2. Year and season of death

Among the 7 dead trees collected from Chibatmok, 5 were *A. koreana* and the other 2 were *Taxus* spp. and *Fraxinus* spp. Therefore, cross-dating to date the death year was conducted with only *A. koreana* which has the site chronology. By comparing the individual ring-width time series of dead trees with site chronology, the death years were successfully verified between 2012 and 2014 (Table 3). Although the *t*-values of 2 trees (JCBKD05 and 07) were low, their annual variation patterns were synchronized up to higher than 60%. Furthermore, presence of earlywood in the outermost tree ring of JCBKD05 and 07 and incomplete latewood in the outermost tree rings of JCBKD02 and 04 signified that the death seasons were between spring and early summer for the former and between late summer and autumn for the latter.

Among the 4 dead trees at Jangteomok, 2 were *A. koreana* and 2 were *P. jezoensis*. Comparing the individual ring-width time series of the dead trees with the corresponding site chronologies, it was verified that the death of *A. koreana* and *P. jezoensis* occurred during 2014–2021 (Table 4). According to *t*-value and G value, the synchronization patterns between the individual ring-

Table 3. The *t*- and G values of death years and seasons for the dated dead *Abies koreana* (JCBKD) between their individual ring-width time series and corresponding master chronology at Chibanmok

ID	No. of tree rings	*t*-value	G value	Outermost annual ring	Bark	Death year / season
JCBKD02	80	4.8	76	LW	B	2014 / late summer–autumn
JCBKD04	89	4.9	64	LW	B	2013 / late summer–autumn
JCBKD05	90	1.6	71	EW	B	2012 / spring–early summer
JCBKD06	82	6.1	67	EW	–	2003 / –
JCBKD07	55	1.3	61	EW	B	2013 / spring–early summer

LW: part of latewood, EW: earlywood.

Table 4. The *t*- and G values of death years and seasons for the dated dead *Abies koreana* (JJTKD) and *Picea jezoensis* (JJTJD) between their individual ring-width time series and corresponding master chronology at Jangteomok

ID	No. of tree rings	*t*-value	G value	Outermost annual ring	Bark	Death year / season
JJTJD01	95	4.2	71	cLW	B	2020 / late autumn–2021 spring
JJTKD02	147	1.3	68	EW	B	2014 / spring–early summer
JJTJD03	364	7.9	66	EW	-	2016 / –
JJTKD04	154	3.8	73	EW	B	2019 / spring–early summer

cLW: completed latewood, EW: earlywood.

width time series and the corresponding chronologies were higher than those at Chibatmok. Based on the development of wood cells in the outermost tree ring with bark, it was verified that *P. jezoensis* died between late autumn and the spring of the next year and *A. koreana* between spring and early summer.

The dead trees at Chibatmok and Jangteomok fell with their roots exposed within the landslide-affected area. Tree roots absorb moisture and inorganic nutrients from the soil. The roots particularly act as carbohydrate reservoirs from where the stored carbohydrates are utilized in various processes, such as vigorous cell division areas (buds, root meristems, cambium, fruits, etc.), energy supply for metabolic activities, and conversion into storage materials like starch (Pallardy, 2010). The present study found that death at the Chibatmok and Jangteomok sites occurred during 2012–2014 and 2014–2021, respectively. Therefore, the death would be the result of the root exposure by the landslide in 2012. According to a previous study, the death of trees at landslide sites occurred in the same year of the landslide or within maximum 3 years of the landslide (Šilhán, 2017). The results from Chabatmok were akin to the cases of the previous study. However, the death of the trees at Jangteomok begun 3 years later than the landslide and ceased after 10 years. A possible cause for the experimental trees at Jangteomok to be able to grow for the next 10 years even after root exposure might be the trees could use the nutrients stored in their roots or it depended on their vitality degree. What has to be considered further, the trees can fall due to an additional landslide after the landslide in 2011.

3.3. Growth reduction

Out of the 14 living *A. koreana* in Chibatmok, all but two showed abrupt growth reduction at least once during their living (Fig. 4). Generally, 29% trees displayed growth reduction in 1950s and 71% in 2010s. Although most trees showed growth reduction in 2010s, the growth conditions for a couple of years before the landslide in 2011 were normal. The abrupt growth decline occurred

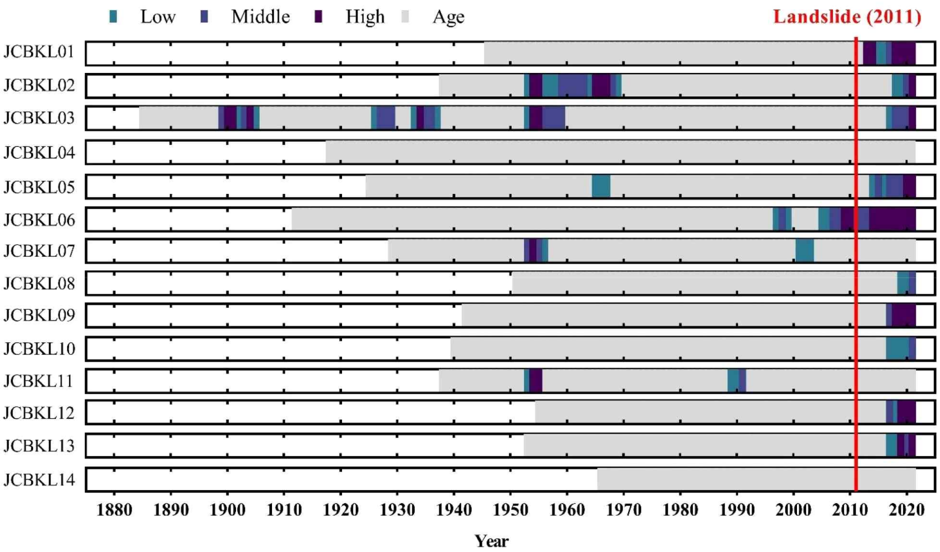

Fig. 4. Abrupt growth reduction periods of the living trees (*Abies koreana*) at Chibanmok.

mainly after the landslide. The dead *A. koreana* within the landslide area showed stronger growth reduction than the living ones and 1 (JCBKD06) of 5 trees died before the landslide (Fig. 5). Except the dead tree, however, the trees did not exhibit any growth reduction in 40 years prior to the landslide.

In Jangteomok, the living *P. jezoensis* showed more growth reduction than *A. koreana* before the landslide in 2011, although the growth reduction in recent years occurred more in *A. koreana* (Fig. 6). Moreover, except

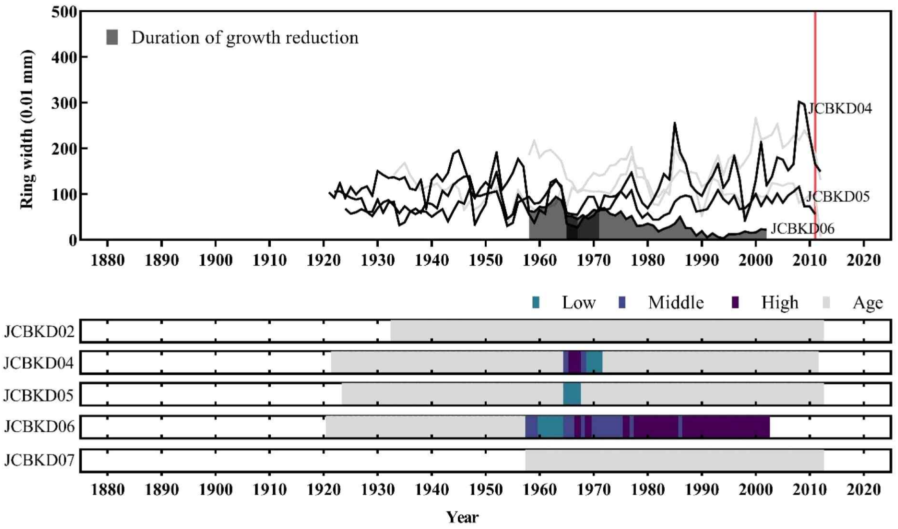

Fig. 5. Abrupt growth reduction periods of dead trees (*Abies koreana*) at Chibanmok site. The black time series are the trees that have abrupt growth reduction, grey ones are the trees that have no abrupt growth reduction, and red line is the occurrence year of landslide.

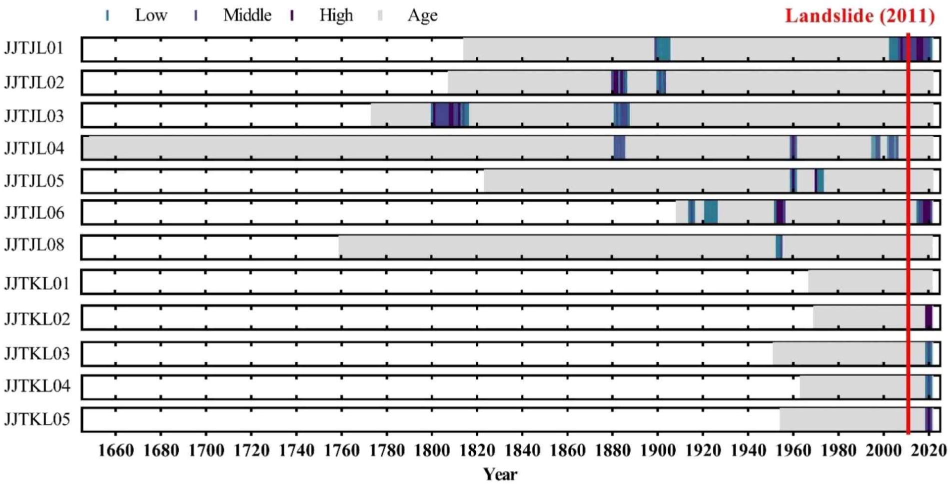

Fig. 6. Abrupt growth reduction periods of living trees (*Picea jezoensis* and *Abies koreana*) at Jangteomok site.

one *A. koreana*, the other living trees showed the growth reduction at least ones during their living. On the other hand, among the 4 dead trees, one from each species showed abrupt growth reduction while they were alive, whereas the other 2 showed none during their living (Fig. 7).

Overall, the living trees near the landslide sites at Chibatmok and Jangteomok showed lower abrupt growth reduction than the dead ones at the landslide locations. This can be justified that a landslide occurs where the growing condition is not good. Under such poor growing conditions, root development is not adequate to stabilize and hold the soil. It was also found in the present investigation that the growth of most living and dead trees was very sound before the landslide in 2011.

4. CONCLUSIONS

To conclude, the current study revealed how the occurrence of landslide can be verified using tree-ring analysis technique. The study found that although the growth vitality of the *P. jezoensis* and *A. koreana* near the landslide points at Chibatmok and Jangteomok were better than the vitality at the landslide sites, the growths of the living and dead trees were very favorable for more than a decade before the landslide. Based on the analysis results, it can be concluded that the death of the trees at the landslide sites happened due to the landslide. The finding that the death of the trees occurred 1 to 9 years after the landslide would play an important role in determining the year of any possible landslide event using the tree-ring analysis technique. The possibility that death could happen due to additional landslides should be considered to estimate the year of landslide happening. To develop further related research in Korea, more sufficient samples and/or various landslide areas need to be investigated.

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

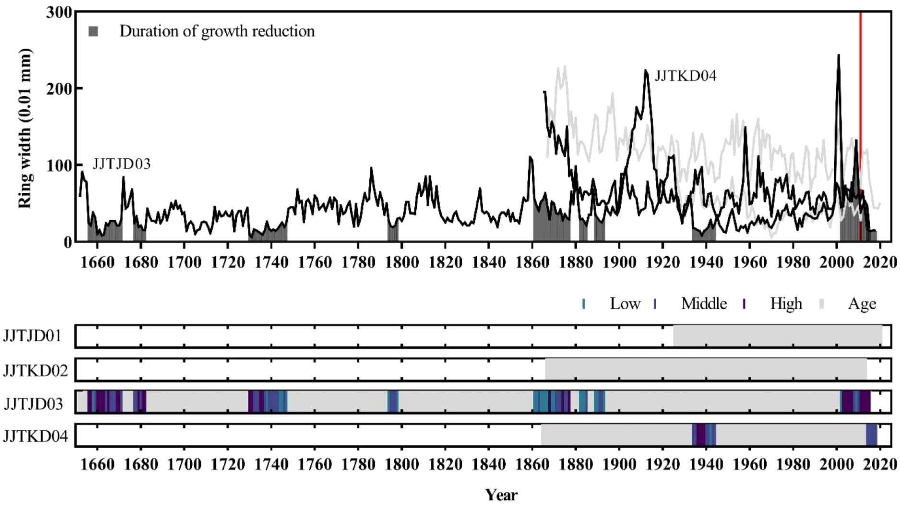

Fig. 7. Abrupt growth reduction periods of dead trees (*Picea jezoensis* and *Abies koreana*) at Jangteomok site. The black time series are the trees that have abrupt growth reduction, grey ones are the trees that have no abrupt growth reduction, and red line is the occurrence year of landslide.

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