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Comparison of growth response of *Abies* and *Picea* species to climate in Mt. Norikura, central Japan

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Abstract Tree-ring chronologies were developed from *Abies mariesii* Masters and *Picea jezoensis* ssp. *hondoensis* (Mayr) P. Schmidt collected at different altitudes of Mt. Norikura, central Japan. The tree-ring parameters of ring width and maximum density were measured by soft X-ray densitometry. The measurement series were detrended by fitting a 33-year cubic smoothing spline and autoregressive model. The correlation between species and between sites showed different responses of the species to climate in terms of ring width and maximum density. The correlation coefficient between sites within a species was higher than that between species for a site in the ring width, and the coefficient between species for a site was higher in maximum density. The correlation coefficient between tree-ring chronology and monthly climate data set showed different responses of radial growth to climate. The different response was probably explained by the difference in the length of the growing season. High summer temperature increased the maximum density of the two species and the radial growth in *Abies mariesii*. Summer precipitation correlated negatively to maximum density, but it did not affect the ring width of either species. The climatic signals could be extracted from ring-width and maximum-density chronologies of both species.

Key words Dendroclimatology · Subalpine · *Abies mariesii* · *Picea jezoensis* ssp. *hondoensis*

Introduction

Tree growth is generally affected by climate changes, and many researchers have published papers on tree response to climatic change and reconstruction of past climate using tree-ring chronology.[1–3] Many have focused on trees growing under cold or dry climate[4,5] because the tree growth is expected to be more sensitive to climatic changes under a severe condition. In rather wet and warm region of temperate Asia, however, tree growth has been considered not to be as sensitive to climate factors. Thus, study sites were often chosen in high elevations or a northern area, expecting temperature to be a limiting factor of tree growth.[6–9]

The main islands of Japan are located in warm and cold temperate zones e.g. These geographical locations are not advantageous (for the above-mentioned reasons) to obtain good samples for dendroclimatological study, Recent work, however, is gradually extending the possibility of dendroclimatological study in Japan. Sweda[10] developed the ring-width chronology of *Chameacyparis obtusa* Endl. from Mt. Ontake, central Japan, and reconstructed past winter temperatures in the region. Yasue et al.[9] developed the chronologies of *Picea glehnii* Masters in terms of ring width and maximum density and discussed their responses to climate in Hokkaido, northern Japan. D'Arrigo et al.[11] developed ring-width chronology of *Quercus dentata* Thunb. in northeastern Hokkaido and indicated that the climatic signal could be extracted from the chronology. Estimating the effect of climate on tree growth is essentially the basis for dendroclimatology. Only a few species have been surveyed in Japan for developing the chronology to discuss the effect of climate on tree growth.

Natural forests of *Abies* spp. are widely distributed from the central to the northern subalpine region in Japan.[12] Thus, the chronologies of these species present a good possibility to establish a tree-ring network. Although *Picea* spp. are not distributed in as wide a range compared with *Abies* spp., they are the dominant species in the subalpine area. In this study, we developed chronologies of ring width and maximum density for *Abies mariesii* Masters and *Picea jezoensis* ssp. *hondoensis* (Mayr) P. Schmidt from different altitudes in central Japan. The purpose was to examine the potential of using these species for dendroclimatological study, including the response of radial tree growth to climate changes.

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Materials and methods

Sites and sampled trees

Mt. Norikura (3026m above sea level) in central Japan was chosen for the sampling sites of this study (Fig. 1A). The timberline is at 2450–2550m in altitude, and Japanese stone pine [*Pinus pumila* (Parras) Regel] is distributed above the timberline. *Abies mariesii* and *Abies veitchii* Lindl. are the most common tree species in subalpine natural forest around central Japan, and the former appears at higher altitudes than the latter.[13] In some cases, *P. jezoensis* ssp. *hondoensis* is mixed into the subalpine natural forests.

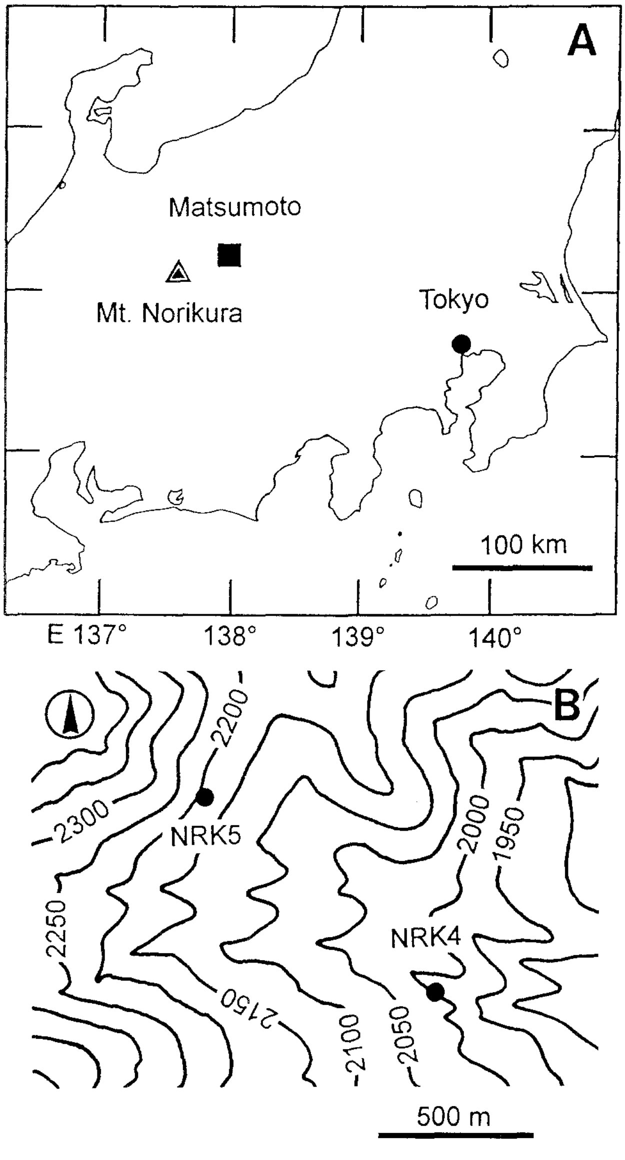

Fig. 1. A Map showing the location of Mt. Norikura and Matsumoto City in which the meteorological station used in this study is located. **B** Sampling sites

Two sampling sites in mixed stands of *A. mariesii* and *P. jezoensis* ssp. *hondoensis* were selected at 2000m (NRK4) and 2200m (NRK5) in altitude on the east slope of the main ridge (Fig. 1B). Because these two sites are located in natural forest, it is believed that no artificial disturbance has affected tree growth. The distance between the sites is so short (ca. 950m on the map) there would be little difference in climate throughout the year except for the temperature difference due to altitude. In 1995 and 1997 two increment cores 5mm in diameter were taken from each tree at breast height using an increment borer. Table 1 gives the details of the sites and sampled trees.

Sample preparation and measurement

The increment cores were mounted in the groove of wood sticks with vinyl acetate emulsion and cut into 1.56 or 2.00mm thick cross sections for soft x-ray densitometry. X-ray negatives were taken for air-dried sections after seasoning in a conditioning room (20°C, 60% RH). The negative films were scanned using Dendro2003 (Walesch Electronic), and ring width and maximum density were measured.

Crossdating

Crossdating was performed by the following three steps. The first step was visual comparison of the densitometric pattern and synchronization of narrow rings (pointer years) among samples. The density fluctuation of the transition zone from earlywood to latewood gave effective information for crossdating. The second step was calculating the moving correlation. Correlation coefficients between each ring-width series of 50-year segments and the total mean series were calculated for every lag year from −80 to +80, and the lag years were listed when significant coefficients were obtained. Before calculation, the individual series of measurements were detrended by 33 years cubic spline filter[14] and prewhitened by fitting an autoregressive model. Steps 1 and 2 were attempted repeatedly until no lag in dating was detected visually or statistically. Finally, the

Table 1. Summary of sites and sampled trees

Code	Site	Location	Altitude (m)	Species	No. of trees
N4A	NRK4	36°06′58″N, 137°35′28″E	1990–2000	*Abies*	5
N4P				*Picea*	7
N5A	NRK5	36°07′18″N, 137°34′59″E	2180–2200	*Abies*	10
N5P				*Picea*	14

Abies, *Abies mariesii* Masters; *Picea*, *Picea jezoensis* ssp. *hondoensis* (Mayr) P. Schmidt.

crossdating was cross-checked by the program COFECHA,[15] which is widely used for statistical confirmation in dendrochronology and dendroclimatology.

Chronology development

To extract climatic signals, measurement series must be detrended to reduce variations due to age trends and natural disturbances. [16] The tree-ring data were detrended by fitting the cubic smoothing spline with 33 years filter length by the program ARSTAN.[14] This filter reduces the amplitude to less than 50% in the range of 33 years and longer frequency.[17] Thus, the filter extracts the short-term variation to examine the climatic signal. Because one of the purposes of this study was to confirm the possibility of extracting climatic signals from tree-ring chronologies, we believed that 33 years was the best filter length to reduce the influence of natural disturbance and age trend. The mean chronology was calculated by biweight robust means for removing the effect of extreme measurements on the mean value.[18] The standard chronologies were prewhitened by fitting an autoregressive model selected on the basis of the first minimum Akaike Information Criterion (AIC) to produce residual chronologies. The residual chronologies are regarded as the chronologies in which the influence of past growth is removed. Thus, climatic signals are expected to be extracted more, as even long-term variation is lost from the chronologies. Both standard and residual chronologies consist of at least three cores for each year.

Climate data

The climate data sets (monthly mean temperature and monthly total precipitation, 1900–1990) observed at Matsumoto Meteorological Station (36°15′06″N, 137°58′04″E, 610m in altitude) were selected for calculating simple correlation coefficients with tree-ring chronologies. The city of Matsumoto is located about 35km eastward of the sampling sites (Fig. 1A). The monthly data set for the 14 months from September of the previous year to October of the current year from 1900 to 1990 was used to calculate the coefficients.

Results and discussion

Chronology

Chronologies of ring width and maximum density were developed for two species at two sites. Because the results of crossdating indicated that no absent or false ring exists in any of the measured cores, the cores were adopted for developing the chronologies. The length of chronologies of N4A, N5A, N4P, and N5P were 128 years (1867–1994), 195 years (1802–1996), 173 years (1824–1996), and 159 years (1838–1996), respectively. The basic statistics for the standard and residual chronologies are shown in Table 2. The mean sensitivity (MS), signal-to-noise ratio (SNR), and mean correlation between trees (MCT) were higher in residual chronologies than in standard ones, which indicated that the common climatic signal was extracted more by fitting an autoregressive model because MS presents the variation due to yearly difference, and SNR and MCT are expressions of the strength of the observed common signal among trees in the ensemble.[17] Therefore, the residual chronologies were used for further analysis in this study (Figs. 2, 3). The similarity of variation in four maximum-density chronologies seems to be high, as the increase/decrease of indices occur synchronously (e.g., in 1866, 1922, and 1994). In contrast, the pointer years of ring width tend to appear differently between species (e.g., 1918, 1936, and 1990 in *Abies* and 1917, 1935, and 1991 in *Picea*). This result suggests that the response of radial growth is different between species even growing in the same sites.

Table 2. Basic statistics of standard and residual chronologies

Parameter	Standard chronology				Residual chronology		
	MS	SNR	MCT	FAC	MS	SNR	MCT
N4A							
Ring width	0.11	1.61	0.24	0.15	0.12	1.84	0.27
Max. density	0.04	0.68	0.12	0.19	0.04	0.67	0.12
N5A							
Ring width	0.13	3.67	0.27	0.35	0.15	4.12	0.29
Max. density	0.05	3.38	0.27	0.13	0.05	3.92	0.30
N4P							
Ring width	0.12	4.07	0.37	0.17	0.15	4.50	0.39
Max. density	0.05	2.27	0.25	0.16	0.05	2.55	0.27
N5P							
Ring width	0.14	9.85	0.41	0.40	0.15	10.61	0.43
Max. density	0.05	8.95	0.39	0.17	0.05	9.10	0.39

MS, mean sensitivity; SNR, signal-to-noise ratio; MCT, mean correlation between trees; FAC, first-order autocorrelation.

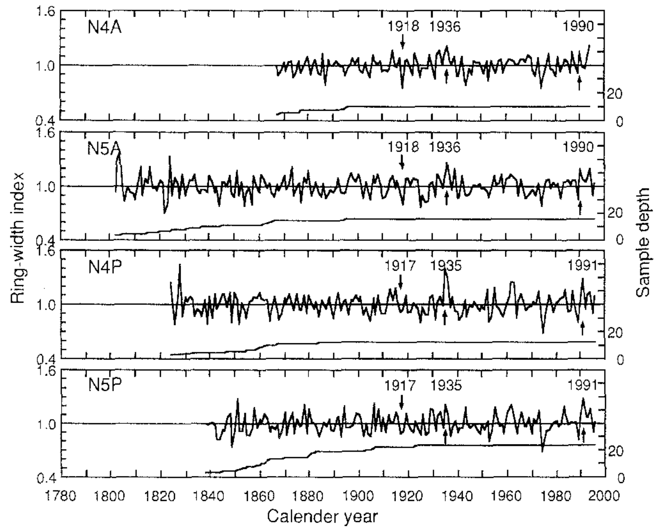

Fig. 2. Residual chronologies of ring width and sample depth. *Arrows* indicate pointer years. The minimum sample depth for each chronologies is three cores

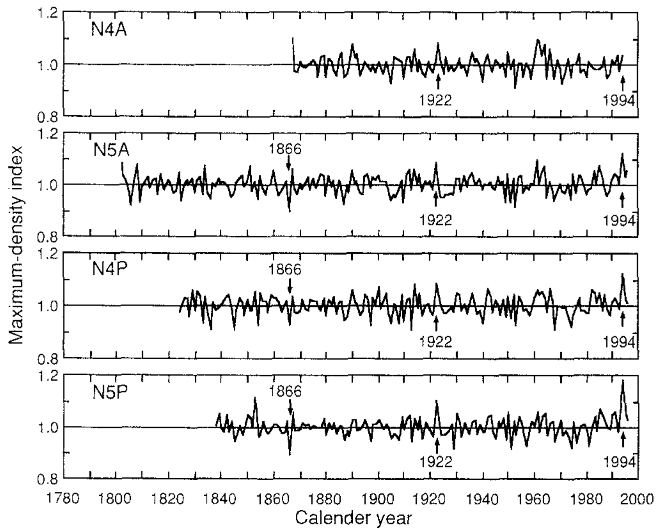

Fig. 3. Residual chronologies of maximum density. *Arrows* indicate pointer years

Table 3. Correlation coefficients between residual chronology from 1900 to 1990 (91 years)

Code	N4A	N5A	N4P	N5P
N4A		0.53	0.60	0.41
N5A	0.68		0.70	0.78
N4P	0.50	0.54		0.72
N5P	0.42	0.53	0.75	

All coefficients are significant at $P < 0.01$. Left bottom half shows correlation coefficients between the ring-width chronologies; right top half shows the correlation coefficients between maximum-density chronologies.

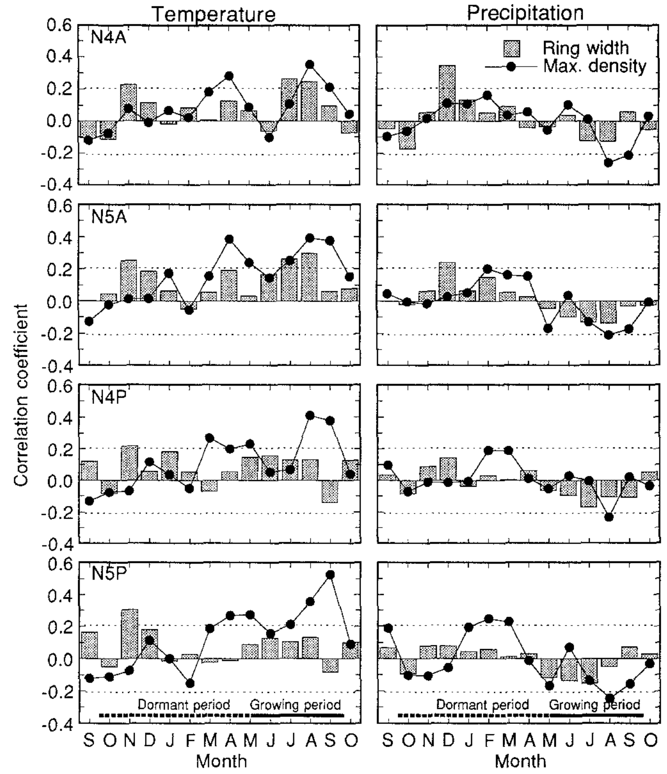

Fig. 4. Correlation coefficients between chronologies and monthly climate data. *Dotted lines* indicate the limit of significance ($P < 0.05$)

Correlation between sites and between species

The correlation coefficients were calculated between sites and between species for ring width and maximum density (Table 3). The length of the chronologies in the calculation was 91 years (1900–1990), in accord with the shortest chronology length of N4A (10 cores for the years 1896–1995).

The correlation of ring width between two sites was highly significant within each species: 0.68 and 0.75 in N4A–N5A and N4P–N5P, respectively (Table 3). The coefficients between species within a site were somewhat smaller than between sites within a species. This result indicated that the growth response to environment was different in each species, although the temperature conditions of their habitats estimated from the warmth index are similar.[19] Graumlich[20] also reported that site-to-site differences are small compared with species-to-species differences in mixed conifer and deciduous forests in the region of relatively small climatic contrast. On the other hand, the coefficient calculated on maximum density between sites within a species was slightly lower than between species within a site. Thus, the factors affecting ring width and maximum density were probably different.

Effect of monthly temperature on radial growth

The correlation coefficients between tree-ring series and monthly climate data are shown in Fig. 4. The correlation coefficients between ring width and temperature during the current growing season (July and August) were significant in two series of N4A and N5A. The positive correlation coefficients between ring width and temperature from April to August were also observed in N4P and N5P, but they were not significant. These results show that the response of radial growth to the climate is different between the species, and *A. mariesii* is more sensitive to summer temperature than *P. jezonensis* ssp. *hondoensis* in this area. Peterson and Peterson[21] reported that the relation between growth and current summer temperature varied in three species of subalpine fir (*Abies lasiocarpa* (Hook. Nutt.), Engelmann spruce (*Picea engelmannii* Parry), and subalpine larch (*Larix lyallii* Parl.); growth of subalpine fir is positively correlated with July–August temperature, whereas that of Engelmann spruce is correlated with June–August temperature. Their results indicate that the duration affecting tree growth is longer in *Picea* than in *Abies*, an observation consistent with our results for *P. jezoensis* ssp. *hondoensis* and *A. mariesii.*

There are some reports on the growing period of *Abies* spp in Japan. Kimura et al.[22] reported that *Abies* trees in Mt. Shimagare sprout their new needles in late June. Kaji[13] also observed that bud burst of *A. mariesii* occurred in the end of June in the subalpine area of Mt. Tengudake. Matsumoto and Negishi[23] reported that the photosynthetic capacity of *A. veitchii* increased immediately as an expansion of leaves in July and reached its maximum in August. Kajimoto (personal communication) reported that the growth period for *A. mariesii* in northern Honshu is from the middle of June to August. These researchers indicated that the growing period of *A. mariesii* and *A. veitchii* in subalpine regions is July and August.

The temperature during the same months positively affected the ring width of *A. mariesii* in our study. The significant correlation between ring-width chronologies and monthly temperature in July and August probably reflects the physiological activity in radial growth. The growing period for *Picea* spp. has been less well investigated compared with that for *Abies*. Chiba[24] reported that bud burst of *P. jezoensis* ssp. *hondoensis* occurs 2 weeks earlier than that of *A. mariesii*, planted at the same place in Hokkaido. Yasue et al.[7] found that initiation of cambial activity for *Picea glehnii* was at the beginning of May in northern Hokkaido. These studies suggested that the growing duration is likely to be longer for *Picea* spp. than for *Abies* spp. in the subalpine regions of Japan. Therefore, the different growth response of the species observed in this study is believed to reflect species-specific growing characteristics, such as timing of cambial reactivation.

Effect of monthly temperature on maximum density

The correlation between maximum density and monthly temperature was higher than that of ring width. The correlation coefficient is positively significant during early spring and the whole summer season except early summer. It was reported that maximum density correlated positively with summer temperature for *Picea glehnii* growing in northern Japan.[9,25] Because summer is the time for latewood formation, the positive influence of temperature is understandable, as activated photosynthesis provides more photosynthates to cambium and a differentiating zone. Warm spring probably stimulates physiological activity to burst buds earlier and induces a longer growing period. Consequently, a larger amount of carbohydrates is allocated for cell wall thickening throughout a growing season. Conkey[26] discussed the contribution of spring conditions to the maximum density of red spruce in Maine (United States). She assumed that early warming in spring permits early physiological activity, thereby providing increased photosynthates for a longer period of time during the growing season. Thus warm or early springs lead to high maximum density.

A species-to-species difference is not clear for maximum density. Because maximum density is generally highly sensitive to summer climate in both *Abies* spp. and *Picea* spp.,[27] our result is interpreted as a response similar for the two species under similar microclimates at the sites. Therefore, it is thought that a site-to-site difference is larger than species-to-species difference for the maximum-density chronology.

Effect of monthly precipitation on ring width and maximum density

Precipitation significantly affected the maximum density negatively during the growing season for all sites and species and for ring width in December for *Abies* (Fig .4). Comparing the number of significant coefficients shows that precipitation had a much weaker influence on tree growth in these two sites. This fact suggests that moisture is not a limiting factor for tree growth in this area, but summer rain could reduce sunlight. The total precipitation at Matsumoto City is only about 1000mm; the precipitation on the high mountain is more than 1000mm for the 3 months from July to September, which is measured at AMeDAS station (36°07′12″N, 137°33′30″E, 2730m) located at Mt. Norikura. Because the station works from mid-June to mid-October, the annual precipitation data are not available for estimating the growth response over a year. Even though the total amount is unknown, the precipitation is expected to be enough for tree growth at the study sites. Sufficient precipitation through the growing season probably resulted in a low correlation between radial growth and precipitation, as the change of precipitation gives less impact on radial growth. Yasue et al.[9] reported that precipitation contributes rarely to the ring width and is not a limiting factor for *Picea glehnii.*

Conclusions

We developed the ring-width and maximum-density chronologies for *Abies mariesii* and *Picea jezoensis* ssp. *hondoensis* from two sites on Mt. Norikura. The species-to-species difference in ring width is larger than the site-to-site difference in this area, and the species-specific response of radial growth to climate is inferred. On the other hand, maximum density is strongly affected by the microenvironment rather than the species characteristics. The ring width and maximum density of the two species are sensitive enough to temperature during the growing season that they are good tools for extracting common climatic signals. Thus, we conclude that both species used in this study are useful for further dendroclimatological study, and the development of longer chronologies promises successful results in the detection of long-term climate changes.

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References

1. Fritts HC (1976) Tree rings and climate. Academic, London
2. Hughes MK, Schweingruber FH, Cartwright D, Kelly PM (1984) July–August temperature at Edinburgh between 1721 and 1975 from tree-ring density and width data. Nature 308:341–344
3. Cook ER, Kairiukstis LA (1990) Methods of dendrochronology: applications in the environmental sciences. Kluwer, Dordrecht
4. Briffa KR, Bartholin TS, Eckstein D, Jones PD, Karlen W, Schweingruber FH, Zetterberg P (1990) A 1400-year tree-ring record of summer temperatures in Fennoscandia. Nature 346:434–439
5. D'Arrigo RD, Barbetti M, Watanasak M, Buckley B, Krusic P, Boonchirdchoo S, Sarutanon S (1997) Progress in dendroclimatic studies of mountain pine in northern Thailand. IAWA J 18:433–444
6. Park WK, Choi WS, Okada N, Fujiwara T, Ahn WY, Ohta S (1995) Dendrochronological study on global warming in Far East: ring width, density and $\delta^{13}C$ analysis of *Pinus koraiensis* from Mt. Sorak. J Korean For Environ 15:1–6
7. Yasue K, Funada R, Noda M, Fukazawa K (1994) Dendroclimatological study of *Picea glehnii* growing in the Teshio experimental forest of Hokkaido University (in Japanese). Res Bull Hokkaido Univ For 51:243–265
8. Yasue K, Funada R, Kondo T, Kobayashi O, Fukazawa K (1996) The effect of climatic factors on the radial growth of Japanese ash in northern Hokkaido, Japan. Can J For Res 26:2052–2055
9. Yasue K, Funada R, Fukazawa K, Ohtani J (1997) Tree-ring width and maximum density of *Picea glehnii* as indicators of climatic changes in northern Hokkaido, Japan. Can J For Res 27:1962–1970
10. Sweda T (1994) Dendroclimatological reconstruction for last submillennium in central Japan. Terrestr Atmos Ocean Sci 5:431–442
11. D'Arrigo RD, Yamaguchi D, Wiles GC, Jacoby GC, Osawa A, Lawrence DM (1997) A kashiwa oak (*Quercus dentata*) tree-ring width chronology from northern coastal Hokkaido, Japan. Can J For Res 27:613–617
12. Franklin JF, Maeda T, Ohsumi Y, Matsui M, Yagi H, Hawk GM (1979) Subalpine coniferous forests of central Honshu, Japan. Ecol Monogr 49:311–334
13. Kaji M (1982) Studies on the ecological geography of subalpine conifers: distribution pattern of *Abies mariesii* in relation to the effect of climate in the postglacial warm period (in Japanese). Bull Tokyo Univ For 72:31–120
14. Cook ER (1985) A time series analysis approach to tree-ring standardization. PhD dissertation, University of Arizona, Tucson
15. Holmes RL (1983) Computer-assisted quality control in tree-ring dating and measurement. Tree Ring Bull 43:69–78
16. Cook ER (1990) A conceptual linear aggregate model for tree rings. In: Cook ER, Kairiukstis LA (ed) Methods of dendrochronology: applications in the environmental sciences. Kluwer, Dordrecht, pp 98–104
17. Cook ER, Briffa KR, Shiyatov S, Mazepa V (1990) Tree-ring standardization and growth-trend estimation. In: Cook ER, Kariukstis LA (eds) Methods of dendrochronology: applications in the environmental sciences. Kluwer, Dordrecht, pp 104–123
18. Cook ER, Shiyatov S, Mazepa V (1990) Estimation of the mean chronology. In: Cook ER, Kairiukstis LA (eds) Methods of dendrochronology: applications in the environmental sciences. Kluwer, Dordrecht, pp 123–132
19. Kira T, Yoshino M (1967) Effects of thermal conditions on habitats of Japanese conifers (in Japanese). In: Morishita M, Kira T (eds) Natural history: ecological studies. Chuokoron-sha, Tokyo, pp 133–161
20. Graumlich LJ (1993) Response of tree growth to climatic variation in the mixed conifer and deciduous forests of the upper Great Lakes region. Can J For Res 23:133–143
21. Peterson DW, Peterson DL (1994) Effect of climate on radial growth of subalpine conifers in the North Cascade mountains. Can J For Res 24:1921–1932
22. Kimura M, Mototani I, Hogetsu K (1968) Ecological and physiological studies on the vegetation of Mt. Shimagare VI. Growth and dry matter production of young *Abies* stand. Bot Mag Tokyo 81:287–296
23. Matsumoto Y, Negishi K (1982) Photosynthesis and respiration in advanced growth *Abies veitchii* growing under a deep canopy and in the open (in Japanese). J Jpn For Soc 64:165–176
24. Chiba S (1961) Time of bud burst in induced *Abies* and *Picea* species (in Japanese). Hokkaido Rinbokuikusyu 4(1):18–22
25. Nobori Y (1994) An analysis of the relationships between weather information and tree ring information of 194 samples from *Picea glehnii* Mast. plantation in the Tomakomai district by X-ray densitometry (in Japanese). J Jpn For Soc 76:89–94
26. Conkey LE (1986) Red spruce tree-ring widths and densities in eastern North America as indicators of past climate. Q Res 26:232–243
27. Schweingruber FH (1993) Trees and wood in dendrochronology. Springer, Berlin