J Wood Sci (2008) 54:183–188
DOI 10.1007/s10086-007-0935-3

ORIGINAL ARTICLE

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On the radial-growth variations of Japanese beech (*Fagus crenata*) on the northernmost part of Honshu Island, Japan

Received: December 6, 2006 / Accepted: November 2, 2007 / Published online: January 13, 2008

Abstract We developed ring-width chronologies for living trees of Japanese beech at two forest sites on the northernmost part of Honshu Island, Japan. A statistical threshold (running expressed population signal) yielded these site chronologies spanning 1853–1994 (142 years) and 1867–1994 (128 years). We examined two factors, climate and masting, that could affect the variations of radial growth. The response function analysis revealed that the ring width correlated positively with July and August temperatures of the previous growth year. The optimal radial growth of Japanese beech may largely depend on a warm previous summer with above-average temperatures. The years of good masting coincided mostly with those showing abrupt growth depression, although only the short-term records of masting were available.

Key words Dendrochronology · Japanese beech · Ring-width chronology · Climate–growth relationship · Masting

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Part of this work was presented at the 6th Pacific Regional Wood Anatomy Conference, Kyoto, December 2005, and the 7th International Conference on Dendrochronology, Beijing, June 2006

Introduction

The radial growth of trees is affected by environmental factors. The fact that cores taken from trees can be reliably crossdated by matching year-to-year variability in tree rings with other samples over large areas is the basis of dendrochronology and dendroclimatology.[1] These areas of investigation provide the possibility of quantitatively estimating the effects of climate change on tree growth. A number of studies have investigated the climatic responses of trees. The results have provided useful information to wood and forest science, paleoclimatology, and many other environmental sciences.

In East Asia, there have been recent efforts to improve the coverage of tree-ring records.[2–7] However, few studies have reported on dendrochronological results particularly for the northeastern part of Honshu Island, Japan, even though several promising long-lived species (e.g., Japanese cedar and Japanese beech) are found there.

Japanese beech (*Fagus crenata* Blume) is widely distributed throughout Japan, and is often the major constituent of cool-temperate deciduous forests. Its northernmost limit is located at the lowlands of the Oshima Peninsula, Hokkaido. Beech-dominated forests are frequently found at the altitudinal range of 200–1400 m asl along the snowy Japan Sea side of the northeastern part of Honshu Island. Many old-growth beech forests are still preserved in a natural condition due to limited use of the wood. On the other hand, beech trees form only small populations in the high mountainous regions in southwestern Japan (e.g., Kyushu Island).

A notable phenological characteristic of beech species is masting, which has long been a controversial issue in forestry and ecology in terms of reproductive strategy.[8] The masting of Japanese beech breaks out a few times per decade, showing a frequency ranging 2–10 years.[9] Several researchers have investigated the possibility of predicting good mast years using climate data and other phenological observations such as the number of winter buds.[10,11]

Hoshino et al.[12] developed a tree-ring network consisting of ten raw ring-width chronologies of Japanese beech in central and northeastern Japan. This work included the intersite correlations within the network and the site-specific signature years for dendroarcheological use. Based on the similarity in the chronologies, they were categorized into four geographical regions over the whole area of the tree-ring network. However, little is known about the factors that affect the change in radial growth.

In the present study, we analyzed the radial-growth variations of Japanese beech using two site chronologies for the northernmost part of Honshu Island. The main objective was to reveal the effect of climate on radial growth of Japanese beech by correlation and response function analyses. We also speculate on a link between masting and abrupt depressions in radial growth.

Materials and methods

Tree-ring records

The tree-ring records were derived from the network of the Japanese beech chronologies for the central and northeastern parts of Honshu Island, Japan.[12] We analyzed the climate–growth relationships for two chronologies at Ohata-Kawauchi (OKC) on the Shimokita Peninsula and one chronology at Masukawa (MSK) on the Tsugaru Peninsula (Fig. 1, Table 1). The sites are located in the northernmost and coldest part in the network, and are therefore expected to show high sensitivity to climate compared with the other sites.[13] At OKC, two raw chronologies were built independently for the forest sites of Ohata and Kawauchi in the previous work.[12] Here, we developed a composite chronology from the raw ring-width series of the two sites annexed, because these are located close to each other (~5 km), and show a highly significant correlation ($t = 10.2$).

The standard techniques of dendrochronology were employed for chronology building.[13] The raw ring-width series were synchronized visually using semilogarithmic graph on a light table.[14] This process of crossdating was later checked statistically using the COFECHA program.[15,16] We computed an ensemble mean (so-called tree mean curve) of the raw ring-width series for each of the sample trees. The tree mean curve was detrended by a cubic smoothing spline with a 50% frequency cut-off of 128 years using the ARSTAN program.[17,18] The series were then standardized by dividing each measured ring width by its expected value. The tree-ring width chronology was computed by applying a biweight robust mean. Finally, the standard and residual versions of the chronology were produced for each forest site. The expressed population signal (EPS) was used to determine the cut-off point in the earlier part of the chronologies. An EPS value of 0.85 was suggested by Wigley et al.[19] as a reasonable threshold for acquiring a robust mean function that represents a reliable population signal. The running EPS was derived from the mean correlation between the 50-years windowed series (RBAR) with 25-year overlaps.

Climate records

Climate records in this region are provided from two meteorological stations, Mutsu (41°17′ N, 141°13′ E, 3 m asl) and Aomori (40°49′ N, 140°46′ E, 3 m asl), of the Japan Meteorological Agency[20] (see Fig. 1). The regular observations started in 1947 (Mutsu) and 1886 (Aomori). Mutsu is the nearest to the forest sites (particularly to OKC), and is hence generally suitable for the climate–growth response analysis. However, even the maximum time span for the

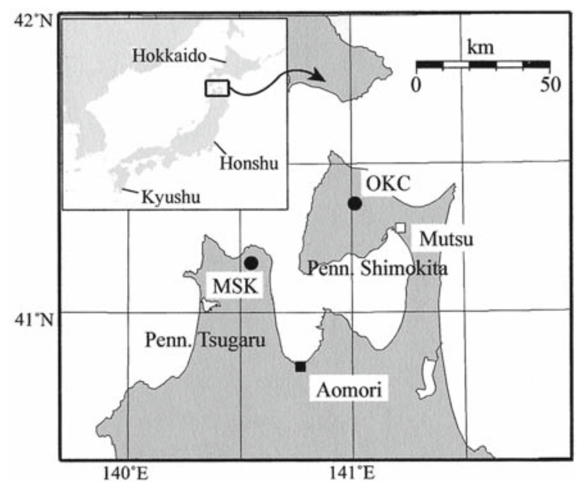

Fig. 1. Map showing the forest sites (*solid circles*) and the meteorological stations (*squares*). The Aomori station (*solid square*) was used for analysis. *OKC*, Ohata-Kawauchi; *MSK*, Masukawa

Table 1. Summary of forest sites and meteorological stations

Site	Code	Latitude	Longitude	Elevation (m asl)
Forest site				
Ohata	OKC	41°22′ N	141°01′ E	400
Kawauchi		41°19′ N	140°59′ E	150–460
Masukawa	MSK	41°10′ N	140°33′ E	260
Meteorological station				
Aomori[a]	47575[b]	40°49′ N	140°46′ E	3
Mutsu	47576[b]	41°17′ N	141°13′ E	3

[a] This station was used for analysis
[b] International meteorological station code

analysis is too short (only 48 years) to obtain robust statistical results. The monthly records of the two stations are nonetheless very similar, showing correlations of 1.00 ($p < 0.01$) and 0.59 ($p < 0.01$) for the mean temperature and total precipitation, respectively. Therefore, we used the monthly mean temperature and total precipitation at the Aomori meteorological station. The annual mean temperature and annual total precipitation are 10.1°C and 1290 mm, respectively (1971–2000). The horizontal distances from the forest sites are ~65 and ~45 km for OKC and MSK, respectively.

Climate–growth response analysis

The correlation and response functions[21] were calculated between the residual chronology and the monthly climate variables (temperature and precipitation) using the Dendroclim2002 program.[22] The explanatory variables spanned 17 months from May of the previous growth year to September of the current growth. The produit de valeurs propres (PVP) criterion[23] was used to determine the number of principal components whose cumulative eigenvalue product was greater than 1.0. The residual chronology was estimated for OKC and MSK, respectively, using the response function model.[21,24]

Results and discussion

Chronologies

Figure 2 illustrates the raw ring-width series of Japanese beech on the northernmost part of Honshu Island, Japan. At MSK, the long-term variation of the series shows a gradual upward trend, whereas at OKC no distinct increasing or decreasing trend can be seen. The rather characteristic ring pattern of Japanese beech may lie in that the radial-growth variation shows acute depressions at interannual to bidecadal intervals.

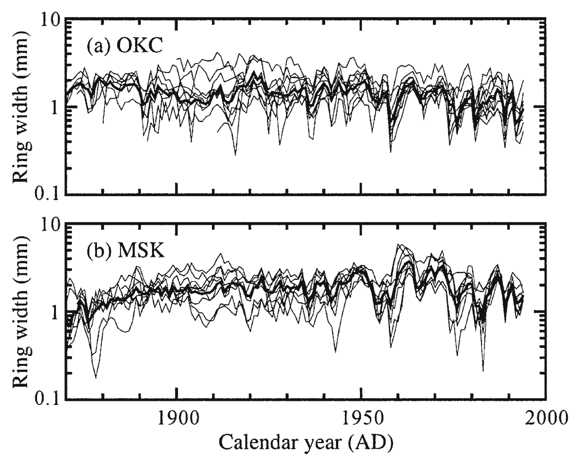

Fig. 2a, b. Raw chronologies (*thick lines*) plotted with individual ring-width series (*thin lines*, tree mean curve) of Japanese beech at **a** Ohata-Kawauchi and **b** Masukawa, northeastern Japan

Figure 3a shows the residual tree-ring chronologies. The 50-years running EPS and RBAR are also presented (Fig. 3b). The threshold EPS value (0.85) yielded the chronologies spanning 1853–1994 for OKC and 1867–1994 for MSK.

Climate–growth model

Figure 4a shows the actual chronologies (residual version) compared with those estimated from the climate–growth models. The chronologies were normalized for comparison. The explained variances of the climate–growth models for OKC and MSK account for 29.9% and 23.7%, respectively ($p < 0.05$). As is usual in linear regression analysis, loss of variance can be observed for the estimated chronologies, particularly for extreme values. A residual analysis[5,25] was performed on the climate–growth models because of the relatively low explained variance of the models. The results (Fig. 4b) show that the residuals (i.e., estimated minus actual values) are statistically independent, fluctuating on an irregular basis.

Effects of monthly climate on radial growth

Figure 5 shows the climatic response of the radial growth of Japanese beech. The ring width correlates positively with

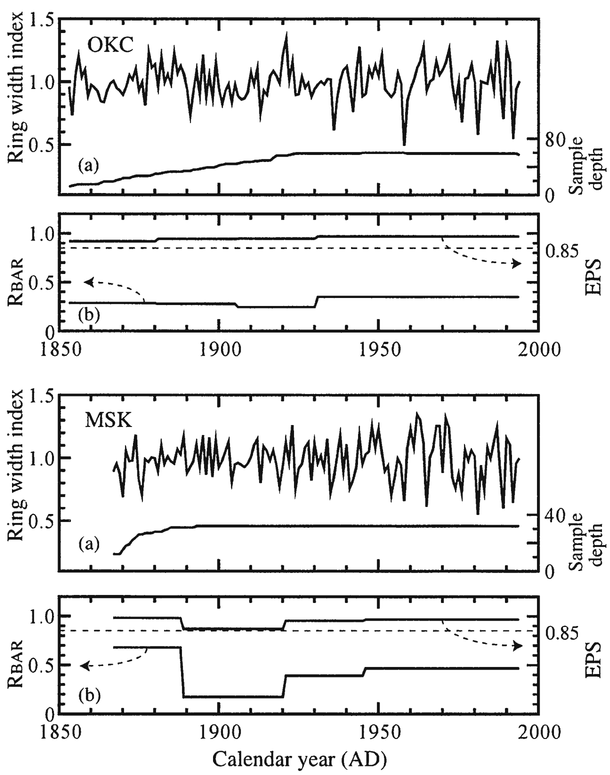

Fig. 3. **a** Tree-ring chronologies (residual version) of Japanese beech at Ohata-Kawauchi (OKC, *top*) and Masukawa (MSK, *bottom*) together with the sample depths. **b** Running mean correlation (*RBAR*) and expressed population signal (*EPS*) statistics based on a 50-year window with 25-year overlaps. *Dotted arrows* indicate relevant axes

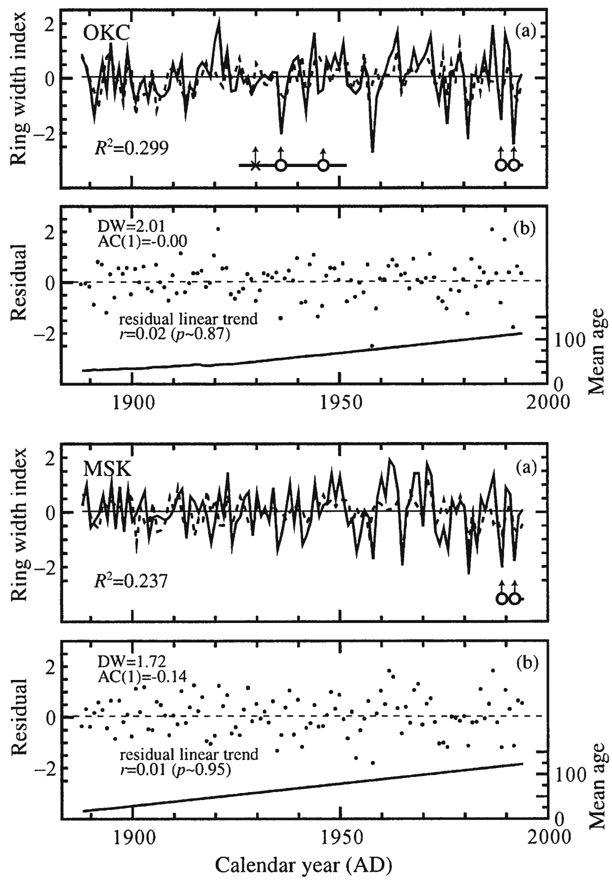

Fig. 4. **a** Comparison of the tree-ring chronologies (*solid thick lines*, residual version) with those estimated from the climate–growth models (*dotted lines*) for OKC (*top*) and MSK (*bottom*). *Arrows* indicate years of masting agreeing/not agreeing with growth depressions (*circles* and *cross*, respectively). *Horizontal lines* under the arrows show the period of continuous observation.[30,31] **b** Mean age for the tree-ring chronologies (*solid lines*) and residual analysis; Durbin-Watson (*DW*) statistic and first-order autocorrelation [*AC(1)*] indicate that the residuals (i.e., estimated minus actual value; *dots*) show no significant serial correlation ($p < 0.01$). Also shown are the linear trends of the residuals (*dotted lines*) and associated *p* values

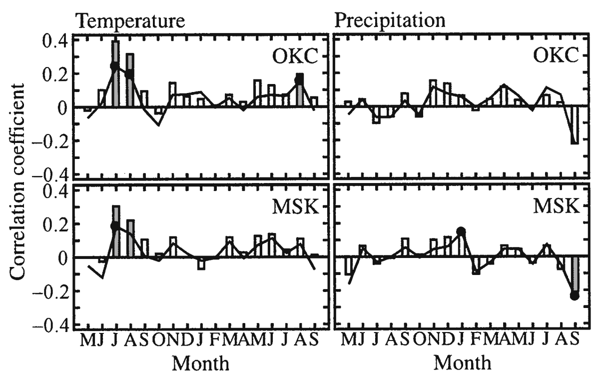

Fig. 5. Responses of the radial growth of Japanese beech to monthly climate; *bars* and *solid lines* show correlation and response functions, respectively. Climate variables significant at $p < 0.05$ are indicated by *solid bars* and *circles*

July and August temperature of the previous year for both OKC and MSK ($p < 0.05$). For OKC, August temperature of the current growth year also showed a positive correlation. No significant correlations were found for precipitation, except for the current September (MSK). Similarly, the response functions support the positive relationship between ring width and temperature of July (OKC and MSK) and August (OKC) of the previous year.

Hence, optimal radial growth of Japanese beech depends on a warm summer with above-average temperatures in the previous year. This lagged effect of summer temperature could be explained by the seasonal dynamics of the allocation of photosynthates. Namely, warmer temperatures in summer facilitate more carbon storage in trees, which can contribute to radial growth in the following season.

The inference above is supported by isotope-labeling (^{13}C and ^{15}N) studies using young common beech (*Fagus sylvatica*). Dyckmans et al.[26,27] revealed that the major fraction of carbon required for lignin production was supplied from plant internal resources and not from recent photosynthates. This was evidenced by the result that the relative allocation of newly assimilated (i.e., current growth year) carbon accounts for only ~18% even at the late stage of growth (18 weeks after bud break). Thus, it is suggested that for Japanese beech the majority of the woody tissues are also formed using carbon stored at least 1 year before.

Abrupt growth depressions in the Japanese beech chronologies

The raw ring-width series (Fig. 2) often show strong growth depressions. As shown in Fig. 4a, these result in large deviations between the actual and estimated chronologies. The residual analysis suggested that the signal component not explained by monthly climate would occur due to some event-type phenomenon. These sporadic events are generally found after the mean age of the chronologies exceeds ~50 years. This is consistent with the fact that Japanese beech begins masting at about 40–50 years of age.[28,29]

Hereinafter, we focus on the acute depressions in our chronologies rather than on the growth releases that show relatively broad peaks. So far as our bibliographic search for the phenological events of Japanese beech, the masting records close to our forest sites were available between 1926 and 1951 on the Shimokita Peninsula (OKC) and between 1989 and 2000 on the both Shimokita and Tsugaru Peninsulas (OKC and MSK).[30,31] In Fig. 4a, arrows indicate good mast years, and open circles show those associated by growth depressions. Good masting was observed five times (1930, 1936, 1946, 1989, and 1992) at OKC and twice (1989 and 1992) at MSK. The recent mast years in 1989 and 1992 coincide with those for the depressions at both forest sites. At OKC, the masting in 1936 and 1946 agrees with growth depression, whereas the 1930 masting does not. Masting was not observed for the 1943 growth depression. In total, the marked depressions coincide with six out of seven mast years. This suggests that in masting years, the photosynthates may be allocated more to seeding rather than radial growth. However, the result may not provide decisive evidence. Although most of the masting events coincide with abrupt growth depressions, the number of masting events (i.e., sample size) is too small to verify the relevance. Further accumulation of phenological and more recent tree-ring records is necessary to better understand such a phenomenon.

Conclusions

We investigated the radial-growth variations of Japanese beech on the northernmost part of Honshu Island, Japan. The tree-ring width chronologies were developed at two forest sites, spanning 1853–1994 at OKC and 1867–1994 at MSK. The raw ring-width series showed abrupt growth depressions at interannual to bidecadal intervals. The years of masting agreed mostly with those of the growth depression, although further accumulation of phenological and tree-ring records is necessary to better understand the relationship between radial growth and masting. The climate–growth response analysis suggested that the optimal growth of Japanese beech largely depends on above-average temperature in the previous summer. This report presents the first dendroclimatological results for northeastern Honshu Island. A recent study[32] suggests that the Japanese beech chronologies can be extended further into the past using cultural properties. Therefore, on the basis of the dendroclimatological results, it is worth examining the potential of the chronologies as a proxy for reconstructing past climate variability.

Acknowledgments This study was partly supported by the Fujiwara Natural History Foundation (to YH), the Circle of the Promotion of Science and Engineering (grant no. H17-3 to YH), and the Japan Society for the Promotion of Science (grant no. 19540493 to HY). The authors thank Prof. Dieter Eckstein, University of Hamburg, and Dr. Motonari Ohyama, Tohoku University, for their helpful review of the manuscript.

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