Radiocarbon, Vol 00, Nr 00, 2023, p 1–9 DOI:10.1017/RDC.2023.50
Selected Papers from the 24th Radiocarbon and 10th Radiocarbon & Archaeology International Conferences, Zurich, Switzerland, 11–16 Sept. 2022

RADIOCARBON DATING OF TREE RINGS FROM THE BEGINNING AND END OF THE YAYOI PERIOD, JAPAN

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ABSTRACT. We have conducted radiocarbon (^{14}C) dating of Japanese tree rings from 1053 to 921 BCE and 41 BCE to 130 CE. Dating was also performed using oxygen isotope dendrochronology to investigate subtle structures of the calibration curve corresponding to the beginning and the end of the Yayoi period in Japan. These two results followed IntCal20, which included the ^{14}C ages of two Japan-sourced trees. The findings suggest that dating of specimens obtained from areas around the Japanese archipelago may be affected by periodic monsoons from the ocean, an effect that needs further examination.

KEYWORDS: monsoon, radiocarbon age, regional effect, tree ring, Yayoi period.

INTRODUCTION

The Yayoi period (Figure 1) is a critical age for Japanese archaeology. At the beginning of this period wet paddy rice cultivation was introduced in northern Kyushu island of the Japanese archipelago and new farming implements and a new type of pottery called Yayoi Pottery appeared. The creation of irrigated rice paddies required extensive construction, leading to conflicts over water and land, which drove changes in societal organization and leadership. During the Yayoi period, people changed their way of life from hunting and gathering to farming.

Archaeologists have long believed that iron tools were introduced along with paddy rice cultivation around the beginning of the Yayoi period, which was considered to be around the 5th century BCE. However, accelerator mass spectrometry radiocarbon (AMS-^{14}C) dating of materials related to early paddy field remains revealed that paddy rice cultivation had begun in northern Kyushu by the 10th century BCE (Fujio et al. 2005; Fujio 2021). This indicates that paddy rice cultivation was introduced earlier than the introduction of iron tools in Japan.

The chronology is still being debated, with some researchers questioning whether ^{14}C dating of Japanese materials can be correctly calibrated with IntCal, which is based on data obtained from Western tree specimens. In response to this criticism, the National Museum of Japanese History (NMJH) has been working on the ^{14}C dating of tree rings from 10th century BCE samples and comparing the data to those of IntCal (e.g., Sakamoto et al. 2003; Ozaki et al. 2007). Some results have been adopted into the latest calibration curve, IntCal20 (Reimer et al. 2020). The shape of IntCal20 covering the period from the 1st to the 3rd century has been revised since the data from Japanese tree rings were included. This period comprises the transition period from the Yayoi to the Kofun period, when large chief tombs were constructed in Japan. The chronology of this period has also been a major research topic in Japanese

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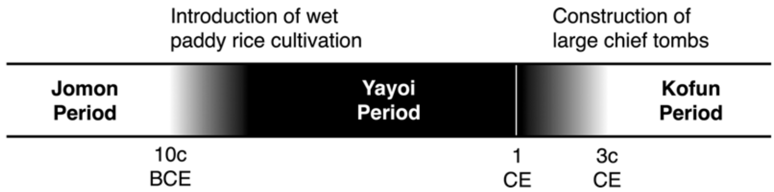

Figure 1 Archaeological chronology of the mainland of the Japanese Archipelago. "Jomon" means cord-marked decoration found on the earthenwares in this period. "Yayoi" is the name of the town where different type of earthenwares from Jomon were excavated. "Kofun" means old burial mounds that were constructed in large numbers in this period.

archaeology. However, the trends observed in the ^{14}C dating of Japanese tree rings may be attributable to regional effects. A better understanding and verification of these trends are required to establish more reliable ^{14}C ages from the Yayoi period.

In the 2010s, a novel dendrochronological dating method using $\delta^{18}O$ of cellulose in annual tree rings was developed in Japan and put to practical use. In humid regions such as the Japanese archipelago, cellulose oxygen isotope ratios are synchronized with annual precipitation. By applying this method, paleoclimate was successfully reconstructed precisely on an annual basis (Nakatsuka et al. 2020). Since precipitation variations are shared across a relatively large area in East Asia, they can also be applied to dendrochronology (Sano et al. 2022), resulting in significant improvements in ^{14}C dating of Japanese tree annual rings (e.g., Sakamoto et al. 2017). Some of the results were included in the new calibration curve, IntCal20 (Reimer et al. 2020), as the first tree ring dated by $\delta^{18}O$. In order to contribute to the chronology of the Yayoi period, we conducted annual ^{14}C dating of two Japanese tree rings.

SAMPLE PREPARATION AND MEASUREMENTS

Two wood samples were obtained from buried trees dating back to the beginning and end of the Yayoi period, respectively (Figure 2). The samples were designated as KGSR002 (from the site in Kagoshima) and MGSNMr-1 (from the site in Miyagi). Although conventional dendrochronological methods could not date these materials, we determined their ages by $\delta^{18}O$ dendrochronology (Table 1).

Cellulose extraction from tree rings was carried out by NMJH using the procedure described by Sakamoto et al. (2017). Buried wood samples were cut into blocks of proper size and polished manually to determine the tree-ring number and widths. The blocks were further polished to a thickness of a few millimeters. After ultrasonic cleaning using acetone and a 2:1 v/v chloroform-methanol mixture, each tree-ring plate was slipped between perforated PTFE sheets and stitched up with PTFE string. The sample was put into a test tube and bleached four times (1 hr each time) with a solution of sodium chlorite and concentrated HCl at 70°C. Hemicellulose was removed using a 17.5 wt% NaOH solution (1 hr, three times at 80°C). After neutralization, the samples were vacuum freeze-dried. Bleached annual rings were separated under a microscope and stored in pre-baked glass tubes.

Annual ring cellulose was divided into aliquots of about 0.1 mg and wrapped in 7 mm × 7 mm silver foil square for $\delta^{18}O$ measurement. The measurement was performed using a continuous flow mass spectrometer coupled to a pyrolysis-type elemental analyzer at Nagoya University.

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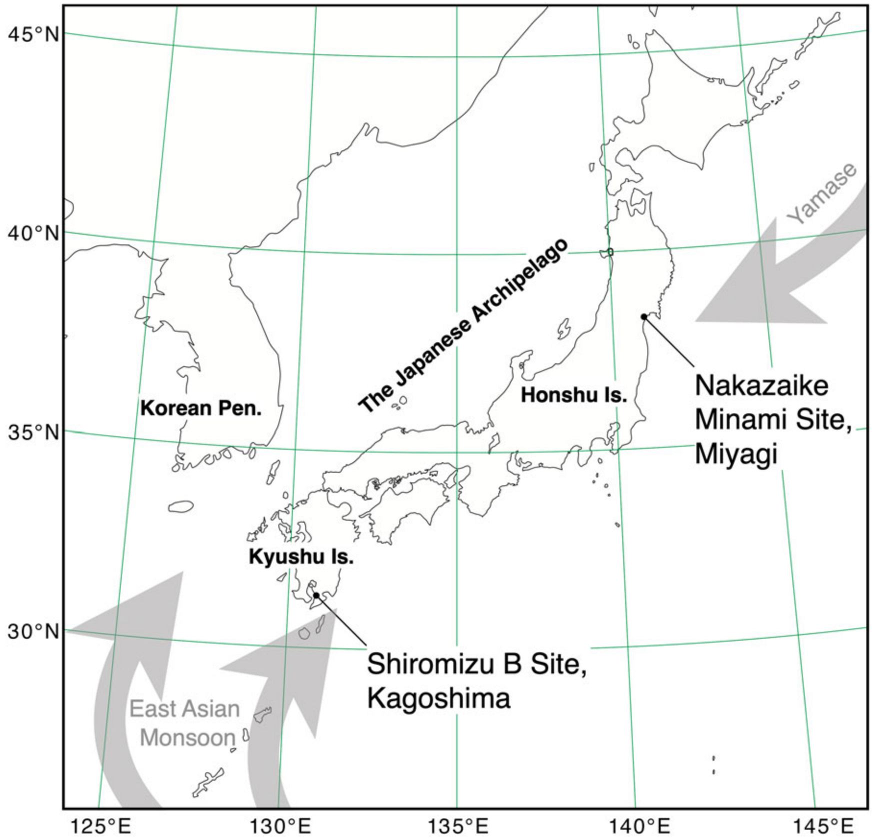

Figure 2 Locations of the sites where the samples used in this study were excavated. Typical directions of summer monsoons around the Japanese Archipelago are also indicated.

Age determination by $\delta^{18}O$ was compared with the master chronology of central Japan. The $\delta^{18}O$ variation of KGSR002 was found to be perfectly synchronized with that of a second KGSR sample, and their average value was compared to the master chronology.

Graphitization of the remaining annual ring cellulose was carried out at the Laboratory of Radiocarbon Dating, the University of Tokyo, which also performed AMS ^{14}C measurements. The tabulated tree-ring ^{14}C ages of this study are presented in the supplemental material. To examine the repeatability of the measurements, some of the annual rings of KGSR002 were measured two or three times. Except for a couple of cases, most results were within the measurement error of below ±25 ^{14}C years.

RESULTS AND DISCUSSIONS

KGSR002: 1053–921 BCE

This sample is a buried Japanese bead tree excavated from the Shiromizu B site in Kagoshima Prefecture in the southwestern region of the Japanese archipelago. Preliminary ^{14}C dating returned an age of 2820 ± 30 ^{14}C BP (IAAA-143218), suggesting that the sample dates to around the 10th century BCE. ^{14}C measurement was carried out after determining tree-ring age

Table 1 List of samples for annual ^{14}C measurement.

Sample	Species	Location	$\delta^{18}O$ dendrochronology	Annual ^{14}C measurements
KGSR002	Japanese bead tree (*Melia azedarach*)	Shiromizu-B site, Kagoshima. 31°23'N, 130°48'E	2974–2876 BP, n = 99 r=0.421, tBP=4.31 (see text)	3002–2870 BP (1053–921 BCE)
MGSNMr-1	Japanese zelkova (*Zelkova serrata*)	Nakazaike-Minami site, Miyagi. 38°14'N, 140°56'E	1991–1820 BP, n=172 r=0.533, tBP=8.22	1990–1820 BP (41 BCE–130 CE)

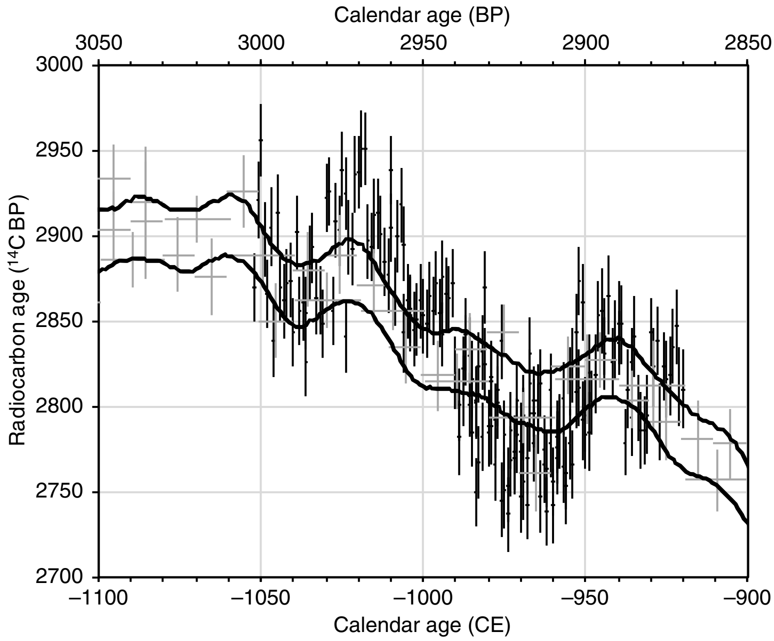

Figure 3 Comparison between ^{14}C ages of KGSR002 (black data points with uncertainties), IntCal20 (solid lines), and the original datasets of IntCal20 (gray data points with uncertainties).

using $\delta^{18}O$. The results are shown in Figure 3, along with the ±1σ of the IntCal20 calibration curve and original datasets cited from https://www.intcal.org.

The data from this period used in IntCal are coarse and the calibration curve is relatively gentle. However, the behavior of KGSR002 shows a clear trend of ^{14}C concentrations during this period. That is, the period around 1000 BCE shows ^{14}C ages that are older than expected, while the period after that exhibits ^{14}C ages on the lower side of the calibration curve. The age deviation ΔZ for all samples was calculated according to

$$\Delta Z = \frac{T(t)_{sample} - T(t)_{IntCal}}{\sqrt{\sigma(t)^2_{sample} + \sigma(t)^2_{IntCal}}}$$

where ΔZ is the normalized difference, T_{sample} and T_{IntCal} are respectively the ^{14}C ages of the tree-ring sample and the corresponding IntCal of t, and σ_{sample} and σ_{IntCal} are their respective uncertainties. A histogram of the age deviation values is shown in Figure 4. The ΔZ data were fitted to a normal distribution using the least-squares method; the resulting distribution has a central value of 0, but consists of two overlapping peaks with different centers. Clarifying the detailed behavior of the calibration curve is expected to lead to more precise dating methods, such as the ^{14}C-wiggle matching (Pearson 1986).

MGSNMR-1: 41 BCE–130 CE

This sample is a buried Japanese zelkova excavated from the Nakazaike Minami site in Miyagi Prefecture northeastern Honshu island of the Japanese archipelago. Preliminary ^{14}C dating

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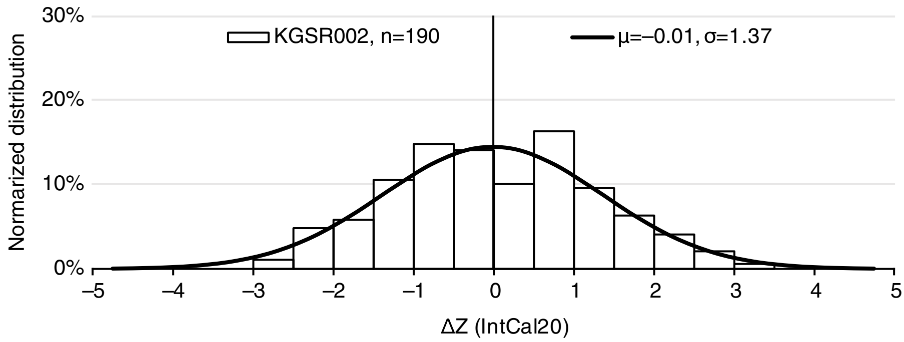

Figure 4 Normalized distribution of differences (ΔZ) between ^{14}C ages of KGSR002 and IntCal20. The solid line shows the best fit to a normal distribution.

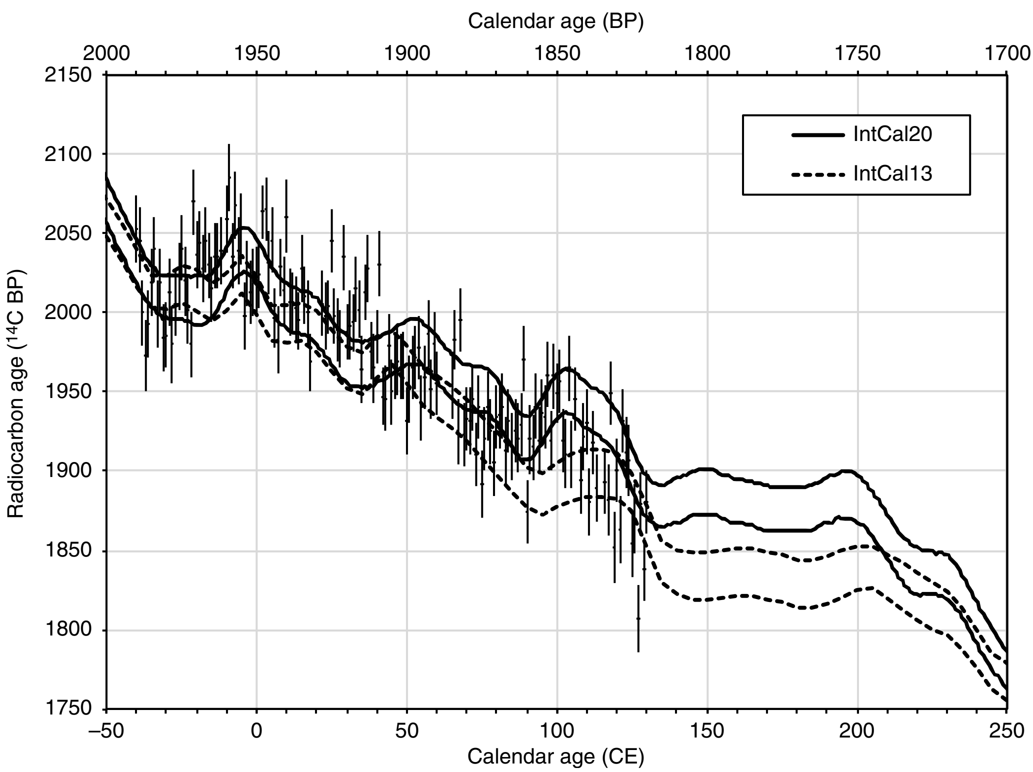

Figure 5 Comparison between ^{14}C ages of MGSNMr-1 (data points with uncertainties), IntCal20 (solid lines), and IntCal13 (dashed lines).

returned an age of 1826 ± 26 ^{14}C BP (Beta-361508). Annual ^{14}C measurement was carried out after determining tree-ring age by $\delta^{18}O$. The results are shown in Figure 5, along with the ±1σ of the IntCal20 and IntCal13 (Reimer et al. 2013) calibration curves.

The shape of the IntCal20 calibration curve for this period was modified using the cedar (246 BCE–200 CE) and the cypress (52–542 CE) data from central Honshu island (Reimer et al. 2020).

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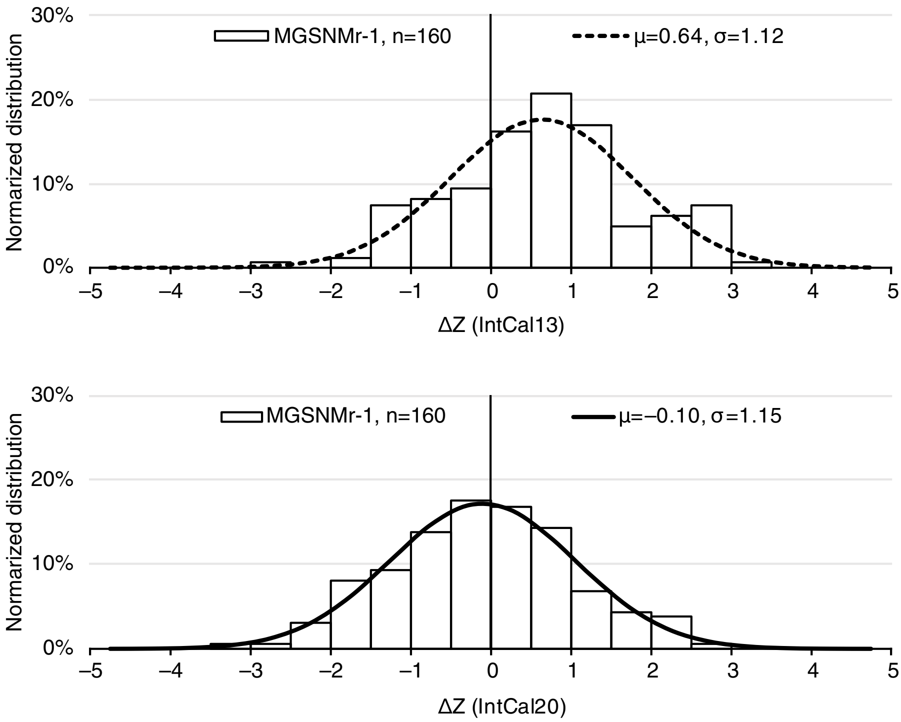

Figure 6 Normalized distribution of differences between ^{14}C ages of MGSNMr-1 and IntCal13 (above) and IntCal20 (below). The solid and dashed lines show the best fit to a normal distribution for each calibration curve.

In both cases, however, five or ten annual rings were used as a single measurement sample. Figure 6 shows a histogram of δZ values compared to the IntCal20 and IntCal13. Although the present measurements did not reach the plateau period of the calibration curve seen in the second half of the 2nd century, the distribution of the δZ values appears closer to that of IntCal20 than IntCal13. However, the first half of the 2nd century is equivalent to IntCal13.

The behaviour of ^{14}C concentrations in the atmosphere around the Japanese archipelago has often been discussed. Kigoshi and Hasegawa (1966) measured the annual rings of the cedar, Yakusugi, on Yakushima Island located south of Kyushu Island and found that the ^{14}C concentration was 0.5% to 1% lower than that of tree rings from Arizona and California during the same period, suggesting the possible influence of the ocean. Nakamura et al. (2013) also measured Yakusugi cedar and other Japan-sourced trees. They showed that the ^{14}C concentration in the atmosphere around the Japanese archipelago is positioned between the Northern Hemisphere (IntCal) and the Southern Hemisphere (SHCal), suggesting the involvement of the Pacific High caused by solar activity.

Monsoons around the Japanese archipelago may bring low atmospheric ^{14}C concentrations from the Pacific ocean. They include the East Asian monsoon, which brings a rainy season to East Asia in the summer; typhoons over the western Pacific, which carry strong winds and heavy rainfall; and the cool monsoon called Yamase, which blows from the North Pacific to northeastern Japan during the summer. Hakozaki (2013) has conducted ^{14}C dating of biennial

https://doi.org/10.1017/RDC.2023.50 Published online by Cambridge University Press

tree rings from the northernmost part of Honshu Island and found that the estimated ages around 1400 CE about 35 years older than those given by IntCal on average, suggesting that the Yamase may have had an effect. On the other hand, Hong et al. (submitted) measured the ^{14}C ages of annual tree rings excavated from the southern coast of the Korean peninsula in the 1st and 2nd centuries. They found that ages given by ^{14}C dating were relatively close to those given by IntCal13 or were between the IntCal13 and IntCal20 values. The latitude of both regions is almost the same and both areas are similarly affected by the East Asian monsoons and typhoons. Atmospheric ^{14}C concentration in these East Asian sites may be influenced by the distance from the North Pacific, which would reflect the influence of the Yamase. To elucidate this, areal ^{14}C dating of tree rings from East Asia is required.

CONCLUSIONS

^{14}C dating of Japanese tree rings in specimens from around 1000 BCE and around 100 CE was conducted. These periods mark the beginning and the end of the Yayoi Period, a pivotal era that is important to Japanese archaeology. Knowing the detailed behavior of ^{14}C dating during these periods helps construct a more accurate chronological perspective. ^{14}C ages obtained from tree rings of specimens from the southern Japanese archipelago dating from the late 11th century BCE were slightly above the IntCal20 calibration curve. In contrast, those from samples dating to the first half of the 10th century BCE tended to be below it.

The ^{14}C ages of tree rings from northeastern Japan around the beginning of the common era show a behavior similar to that of IntCal20, which includes data of Japan-sourced trees. However, ^{14}C ages of tree rings from the southern coast of the Korean Peninsula, located at similar latitude, are relatively close to IntCal13. These variations may reflect the influence of monsoons, which can dilute the atmospheric ^{14}C concentration around the Japanese archipelago from the ocean at different times of the year.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/RDC.2023.50

ACKNOWLEDGMENTS

We are grateful to the Kagoshima Prefectural Foundation for Cultural Promotion, Buried Cultural Property Research Center (KGSR002), and the Sendai City Board of Education and Cultural Property Center of the Pasco Inc. (MGSNMr-1), for providing us with samples. Ms. R. Yamamoto helped us with sample preparation. Ms. Y. Saito reviewed the English text. JSPS KAKENHI Grant Numbers JP18H03594 and JP22H00026 supported this work.

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