Original article

Shuichi Noshiro[1] and Mitsuo Suzuki[2]: *Rhus verniciflua* Stokes grew in Japan since the Early Jomon Period

能城修一[1]・鈴木三男[2]：日本には縄文時代前期以降ウルシが生育した

Abstract In Japan lacquer made of the latex of *Rhus verniciflua* was used since 9000 cal B.P. of the Earliest Jomon Period. Since this period many examples of lacquer ware and remains of lacquer processing have been found throughout Japan. However, there was no botanical evidence that *Rhus verniciflua* trees grew in Japan. Recently, fossil woods of *R. verniciflua* were reported at several sites. *Rhus* fossils have been identified into several species groups based on qualitative features, but the distinction between *R. trichocarpa* and *R. verniciflua* was not studied critically. By comparing mature woods of these two species and studying ontogenetic trends in *R. verniciflua*, we found that the wood of *R. verniciflua* tends to be semi-ring-porous with larger vessels and wider rays up to 4 cells wide, while that of *R. trichocarpa* tends to be ring-porous. Re-identification of *Rhus* fossil woods so far reported based on these features showed that *R. verniciflua* grew in middle to northern Honshu since the Early Jomon Period. Wood of *R. verniciflua* was used as stakes, boards, or bowls, and this tree seemed to have been planted close to settlements for lacquer collection and timber usage since that period.
Key words: Early Jomon Period, Japan, *Rhus verniciflua*, wood identification, wooden artifacts

要　旨　日本でのウルシの使用は縄文時代早期に遡り，漆器のほかウルシの樹液の加工に伴う遺物が縄文時代以降の多くの遺跡で見いだされてきた。さらに縄文時代の漆工技術は，それ以降の時代のものと比べても優れていることが指摘されてきた。しかしウルシの木を遺跡周辺で栽培していたという植物学的な証拠は得られていなかった。この数年，本州の中北部でウルシとされる木材が報告されるようになった。ウルシ属は質的形質でいくつかのグループに同定されてきたが，ウルシとヤマウルシを識別する特徴は明らかでなかった。この 2 種の成熟材の形質およびウルシの個体発生にともなう形質変化を調べたところ，ウルシのほうがヤマウルシにくらべて散孔性が強く，道管径が大きく，放射組織が 4 細胞幅に達することで識別できることが明らかとなった。この形質にもとづいて，これまでに出土したウルシ属の木材を同定しなおした結果，ウルシは縄文時代前期以降，本州の中北部に成育していたことが明らかとなった。見いだされたウルシは杭や板，容器をはじめとする木製品として使用されており，ウルシの木は樹液を採るだけでなく材木としても活用される身近な樹種であった。
キーワード：ウルシ，樹種同定，縄文時代前期，日本，木製品

Introduction

In Japan lacquer made of the latex of *Rhus verniciflua* Stokes (Anacardiaceae), synonymous with *Toxicodendron vernicifluum* (Stokes) F. A. Barkley, is known to be used since the Earliest Jomon Period, and lacquer ware was one of the most important products in Japan since that period. The oldest lacquer found at the Kakinoshima B Site, Hokkaido, along with Monomi-dai pottery, was used as a paint for threads and was radiocarbon dated at 9000 cal B.P. with AMS (Minami-kayabe Town Archaeological Research Group, 2002). This was the oldest record of lacquer usage in the world. Since this period, lacquer ware of wood and pottery and remains of lacquer processing such as sieving cloth clogged with lacquer and pots containing raw or refined lacquer commonly have been found throughout Japan (e.g., Kenjo, 1983; Yamada, 2002). Moreover, the technique of lacquer processing and painting of the Jomon Period was found to be quite refined compared with that of later periods (Iizuka, 2000). However, there has been no report of the seeds, fruits, or woods of *Rhus verniciflua*, and it was not proven that the species grew or were planted in Japan since the Jomon Period. The seeds and fruits of *Rhus* are fragile, and their fragments would not allow identification of *Rhus* species.

Rhus verniciflua has been considered as introduced from China (Shirai, 1929; Hara, 1954; Yamazaki,

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1989; Iwatsuki, 1999), because it does not grow in natural forests of Japan and is found only around human settlements. In China, *R. verniciflua* grows naturally in open forests between 800–2800(–3800) m in altitude of all the provinces except for Heilongjiang, Jilin, Nei Mongol Zizhiqu, and Xinjian Uygur Zizhiqu in the north (Ming, 1980). *Rhus verniciflua* trees usually grow to 10(–20) m tall and 50 cm in diameter, and its light yellow wood was used for marquetry, floats, bow sides, and umbrella handles in Japan during the Meiji Period (Forest Bureau, Ministry of Agriculture and Commerce, 1912).

Recently fossil woods of *R. verniciflua* came to be reported at several sites (e.g., Suzuki et al., 2002 ; Hisada et al., 2002). Fossil woods are usually identified at the levels of genus, subgenus, or section, and identification of species is usually difficult (Noshiro & Suzuki, 1987). However, *Rhus* (sensu lato) has an exceptionally diverse wood structure, and its wood can be identified into several species groups based on qualitative features (Dong & Baas, 1993). Among Japanese species, *R. ambigua* Lavallée ex Dippel has ring-porous wood with thick-walled vessels; *R. succedanea* L. and *R. sylvestris* Sieb. et Zucc. have diffuse-porous wood with sparse thick-walled vessels; *R. javanica* L. has ring-porous wood with tangential bands of small thin-walled vessels in the latewood; and *R. trichocarpa* Miq. and *R. verniciflua* Stokes have semi-ring-porous wood with latewood vessels in radial multiples. *Rhus trichocarpa* and *R. verniciflua* have similar wood structure, and their distinction has not been studied critically in spite of reports of their fossil woods.

Here, we clarify the wood structural distinction between *R. trichocarpa* and *R. verniciflua* by comparing their mature wood and studying ontogenetic trends in *R. verniciflua*. Based on our results, we identify fossil woods of *R. verniciflua*, confirm its presence since the Early Jomon Period, and discuss usage of its wood by ancient people.

Materials and methods

We studied 9 and 12 specimens of extant *Rhus verniciflua* and *R. trichocarpa*, respectively (Table 1). Six specimens of *R. verniciflua* are mature wood from trees over 30 years old, and three are from young trees used for lacquer scraping in the Wajima district, Ishikawa Pref., probably less than 15 years old. All the specimens of *R. trichocarpa* are mature wood from trees up to 45 years old.

Fossil specimens were recovered at seven sites from Aomori in northern Honshu to Tokyo and Ishikawa in central Honshu (Table 2). Among the 47 specimens, five specimens of the Jomon Period (AOM-2575, AOM-3608, SYB-431, SYB-1329, SYB-1350) and three of the Nara to Heian Periods (SYB-410, SYB-417, SYB-423) had an intact growth ring that allowed quantitative analysis of vessel diameter throughout a growth ring. Growth rings of all the other specimens were incomplete or squashed in the middle and not fit for quantitative analysis through a growth ring.

We studied tangential vessel diameter and ray width. Tangential vessel diameter was measured on a microscopic image obtained with a digital camera, Nikon D-100 (Nikon Co., Tokyo, Japan), and analysed with an image analysis software, Image/J (Wayne Rasband, National Institute of Mental Health, Maryland, U.S.A.). All the vessels within a portion of a wide growth ring were measured for each specimen to study within-ring transition of vessel diameter. Narrow growth rings were avoided, because the transition from the earlywood to the latewood was too abrupt in these rings. The studied areas were 1.550–5.085 mm in radial length and 2.006–2.571 mm in tangential width and included 94–353 vessels. Tangential vessel diameter was averaged for six equal parts in the radial length of each growth ring. Ray width in cell number was measured in one tangential section for 34–82 rays per specimen. Ray width was compared as percentages of rays 1–5 cells wide.

In two specimens of *Rhus verniciflua*, TWTw-335 and 336, we also studied ontogenetic trends in the two quantitative features. Vessel size was measured in years 2, 7, 14, 22, 31, and 36 growth rings for TWTw-335 and in years 2, 6, 13, 20, and 30 growth rings for TWTw-336. Ray size was measured in years 4, 9, 12–13, 19, 27, 32, and 37 growth rings for TWTw-335 and in years 4, 7, 10, 16, 25, and 32 growth rings for TWTw-336.

Results

1. Tangential vessel diameter of extant specimens

In the mature wood of *Rhus verniciflua*, large vessels are crowded into several rows in the earlywood, and vessels become smaller and sparser in the latewood (Figs. 2, 4, 5). In the immature wood, rows of large earlywood vessels are fewer than in the mature wood, and vessel density quickly reduces outside these rows (Fig. 1). In mature specimens of *R. verniciflua,* tangential vessel diameter reduced almost linearly from ca. 150 μm in the first-formed earlywood to 30 μm in the final latewood (Fig. 16). In several specimens, the vessel diameter increased or was nearly the same outside the earlywood pore zone, making the transitional curve parabolic. Ontogenetic trends in two specimens

Table 1 Studied specimens of extant *Rhus verniciflua* and *R. trichocarpa*

Specimen No.	Provenace	H (m)	D (cm)	Age
Rhus verniciflua Stokes				
TWTw-31	Meguro, Tokyo, Japan	-	R = 12	32
TWTw-335	Joboji Cho, Ninohe Gun, Iwate, Japan	13	26	37
TWTw-336	Joboji Cho, Ninohe Gun, Iwate, Japan	13	22	32
TWTw-1166	Ootaki Mura, Chichibu Gun, Saitama, Japan	-	> 8	>14
TWTw-4825	Japan	-	> 7	>10
TWTw-13636	Heilongjiang, China	-	R > 7	>56
TWTw-18394	Takahashi City, Okayama, Japan	5	10	30
Kan-9462	Wajima City, Ishikawa, Japan	-	-	-
Kan-9565	Wajima City, Ishikawa, Japan	-	-	11
Rhus trichocarpa Miq.				
TOFOw Chichibu-29	Ootaki Mura, Chichibu Gun, Saitama, Japan	-	-	-
TWTw-3385	Amatsu-kominato Machi, Awa Gun, Chiba, Japan	-	4.2	25
TWTw-15518	Ago Cho, Sima Gun, Mie, Japan	7	5.5	40
TWTw-18033	Nakagawa Cho, Kamikawa, Hokkaido, Japan	4.5	4	21
TWTw-18115	Kuriyama Mura, Shioya Gun, Tochigi, Japan	4.5	7	27
TWTw-18981	Miyagawa Mura, Taki Gun, Mie, Japan	4	8	25
TWTw-19669	Mine Cho, Kamiagata Gun, Nagasaki, Japan	8	12	45
TWTw-19817	Iwaizumi Cho, Shimohei Gun, Iwate, Japan	7	10	27
Kan-9041	Kawauchi Mura, Ishikawa Gun, Ishikawa, Japan	-	-	-
Kan-9050	Kawauchi Mura, Ishikawa Gun, Ishikawa, Japan	-	-	-
Kan-9349	Kakuma, Kanazawa City, Ishikawa, Japan	-	-	-
TI-3989	Yufuin Cho, Ooita, Ooita, Japan	5	12	>17

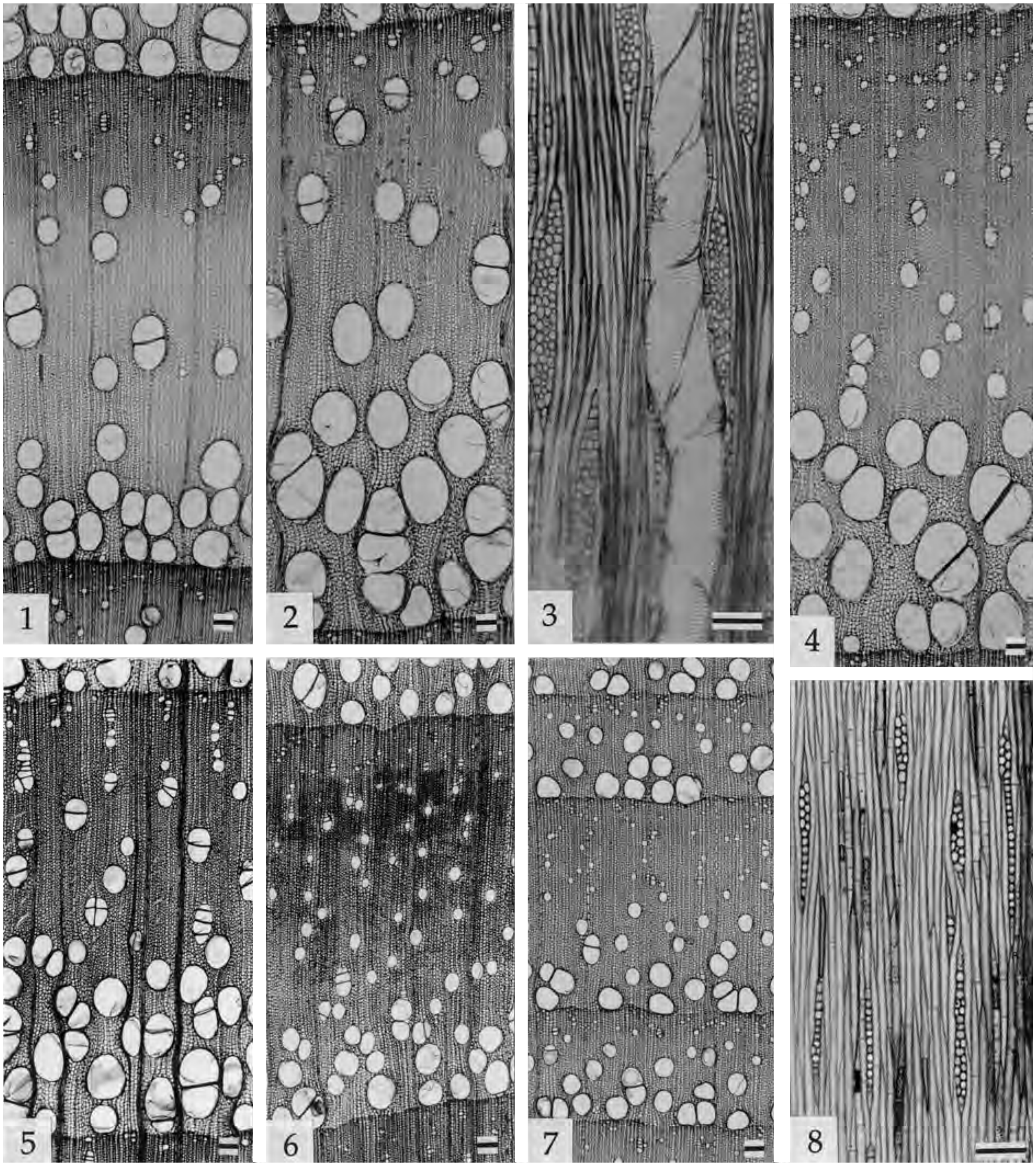
showed that the wood of *R. verniciflua* assumes mature parabolic pattern at 6–7 years old, but that mature vessel size above 170 µm is attained at 13–14 years old (Fig. 16).

In the mature wood of *Rhus trichocarpa*, rows of large earlywood vessels are fewer, and vessels are less crowded than in *R. verniciflua* (Figs. 6, 7). In *R. trichocarpa,* tangential vessel diameter reduces steeply, from ca. 100 µm, in the earlywood and then gradually in the latewood, making the transitional curve inversely exponential (Fig. 16). Although growth ring width varied from 2.2 to 4.6 mm, vessel diameter transition was similar in all *R. trichocarpa* specimens, while it was more varied in *R. verniciflua* specimens. The earlywood vessels of *R. trichocarpa* were on average 50 µm smaller than those of *R. verniciflua*, and, throughout the growth ring, vessel diameter of *R. trichocarpa* was smaller than that of *R. verniciflua*.

Thus the wood of *R. verniciflua* tends to be semi-ring-porous with larger vessels in the range of 28–150 µm, whereas that of *R. trichocarpa* tends to be ring-porous with smaller vessels in the range of 17–97 µm.

2. Ray width of extant specimens

Among the specimens of extant *Rhus verniciflua,* ray width varied greatly (Fig. 17). In four specimens, rays three cells wide were the most common, occupying 40% of all rays examined. In three specimens, rays two cells wide were the dominant type, and in two specimens, rays four cells wide were most common (Fig. 3). In *R. trichocarpa,* ray width is quite uniform, and rays two cells wide were the dominant type, occupying 40–70% in all the specimens, except for two (Figs. 8, 17). In one specimen each, rays one or three cells wide were the most common. In the two *R. verniciflua* specimens used for ontogenetic study, ray width peaked at two cells at 4–5 years old, three cells at 7–13 years old, and at four cells at over 16 years old. In one of these two specimens, rays four cells wide occupied 40–70% over 19 years old, but rays three cells wide were also com-

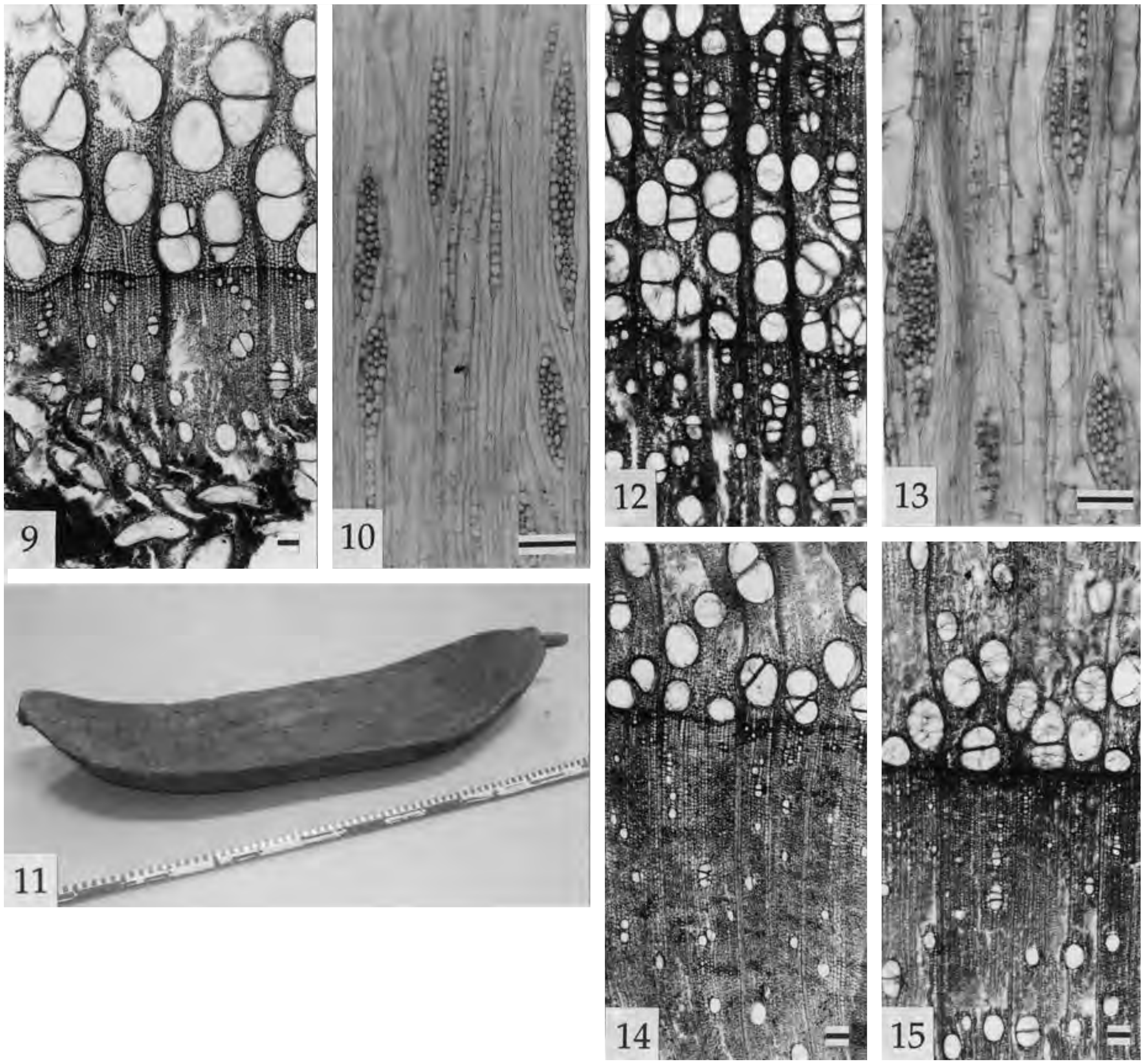


Figs. 1–8 Wood structure of extant *Rhus verniciflua* (1–5) and *R. trichocarpa* (6–8). — 1–3: TWTw- 335; 1: CS, 5 yr growth ring, 2: CS, 34 yr growth ring, 3: TS, 39 yr growth ring. — 4: TWTw-336, CS, 30 yr growth ring. — 5: TWTw-31, CS. — 6: TI-3989, CS. — 7, 8: TWTw-15518; 7: CS, 8: TS. CS = cross section, TS = tangential section, scale bar = 100 µm.

mon over 16 years old in the other. Thus, ray cell width of the two species overlapped, and distinction based on ray width alone was difficult.

3. Identification of fossil *Rhus verniciflua*

Fossil woods attributed to *Rhus verniciflua* tended to have the middle portion of growth rings distorted (Figs. 9, 12, 14, 15). Tangential vessel diameter decreased linearly from ca. 130 µm in the first-formed earlywood to 30 µm in the last-formed latewood (Fig. 16). In several specimens, vessel diameter increased outside the earlywood pore zone forming a parabolic transitional curve



Figs. 9–15 Wood structure of fossil specimens of *Rhus verniciflua* (9, 10, 12–15) and a vessel-shaped bowl (11). — 9, 10: AOM-3610 (vessel-shaped bowl of the Iwatari-kotani 4 Site); 9: CS, 10: TS. — 11: vessel-shaped bowl of the Iwatari-kotani 4 Site (76 cm long, 10 cm wide, with 26 growth rings). — 12, 13: AOM-2575 (natural wood of the Mukoda 18 Site); 12: CS, 13: TS. — 14: SYB-431 (stake/plank of the Shimo-yakebe Site), CS. — 15: SYB-417 (stake of the Shimo-yakebe Site), CS. CS = cross section, TS = tangential section, scale bar = 100 µm.

as in extant *R. verniciflua*. In the middle of the growth ring, vessel diameter of all the specimens was over 60 µm and was more than that of extant *R. trichocarpa*. Ray width peaked at two cells in four specimens and at three cells in the other four (Figs. 10, 13). Ray width variation of fossil *R. verniciflua* was intermediate between that of extant *R. verniciflua* and *R. trichocarpa*.

Discussion

1. Species identification from wood structure

Except for monotypic genera, a limited number of Japanese species can be identified from wood structure. Two examples are *Acer carpinifolium* and *Prunus jamasakura*. *Acer carpinifolium* can be identified by exceptionally large rays with an angular outline among *Acer* species (Ogata, 1967). *Prunus jamasakura* can be distinguished from other *Prunus* species by its larger round vessels often aligned into an oblique pattern (unpublished data). *Rhus verniciflua* and *R. trichocarpa* are additional examples of species that can be identified from wood structure.

In qualitative features, *Rhus verniciflua* and *R. trichocarpa* are quite similar, having semi-ring-porous wood, helical thickenings in latewood narrow vessels,

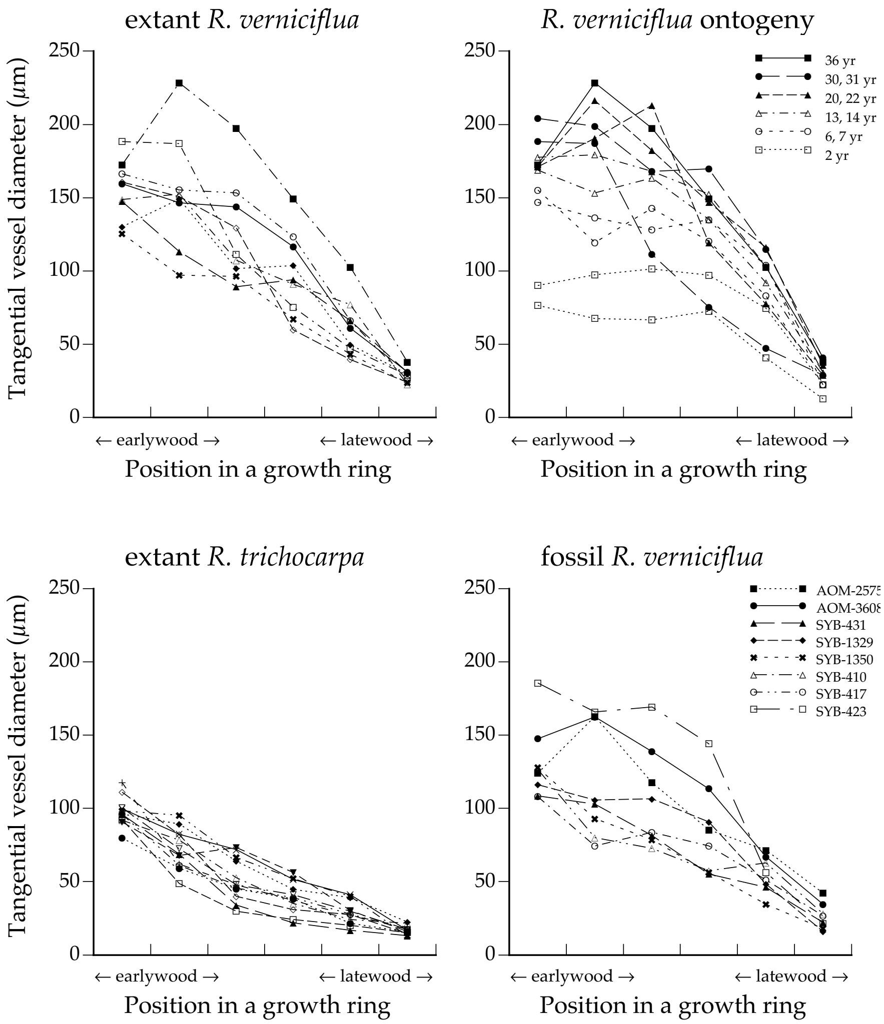


Fig. 16 Transition of tangential vessel diameter through a growth ring. Averages for six parts of a growth ring are compared in extant *Rhus verniciflua*, two extant *R. verniciflua* specimens for ontogenetic study (TWTw-335, 336), extant *R. trichocarpa*, and fossil *R. verniciflua*. For extant *R. verniciflua* and *R. trichocarpa*, specimen numbers are not given. For ontogenetic trends, vessel size was measured in years 2, 7, 14, 22, 31, and 36 growth rings for TWTw-335 and in years 2, 6, 13, 20, and 30 growth rings for TWTw-336.

axial parenchyma that is vasicentric and in terminal bands, and heterocellular rays whose body consists of procumbent cells and occasional upright cells. However, *R. verniciflua* can be distinguished from *R. trichocarpa* in three quantitative features: 1) large crowded earlywood vessels in several rows at the beginning of growth rings, 2) slow or linear reduction in vessel diameter in the middle portion of growth rings, and 3) occasional dominance of rays 3–4 cells wide. Even in immature wood, radial transition of vessel diameter and vessel size in the middle portion of growth rings allow identification of these two species.

To confirm species identification by quantitative features of wood structure, a large number of specimens representing specific variation should be studied. Such work is laborious and often meritless for systematic studies, but is feasible for identification of archaeologically important taxa. As in *Acer carpinifolium* and *Rhus* species, critical bases for species identification should be sought in the future to confirm species identification of archaeological woods.

2. Ancient usage of *Rhus verniciflua* wood

Besides the eight specimens used for the quantitative analysis of vessel diameter and ray width, 39 fossil woods of *Rhus verniciflua* have been identified from seven sites (Table 2). All the specimens are recovered from central to northern Honshu. Twenty-four specimens are of the Early Jomon Period, three each are of the Late and the Latest Jomon Periods, 13 are of the Nara to Heian Periods (Ancient Period in Japan), and four are probably of the Edo Period (Early Modern Period in Japan). Except for eight specimens of the Early Jomon Period and one of the Latest Jomon Period, all are artifacts mostly used for boards, stakes, or planks.

The most elaborate artifacts made of *Rhus verniciflua* wood are two vessel-shaped bowls of the Early Jomon

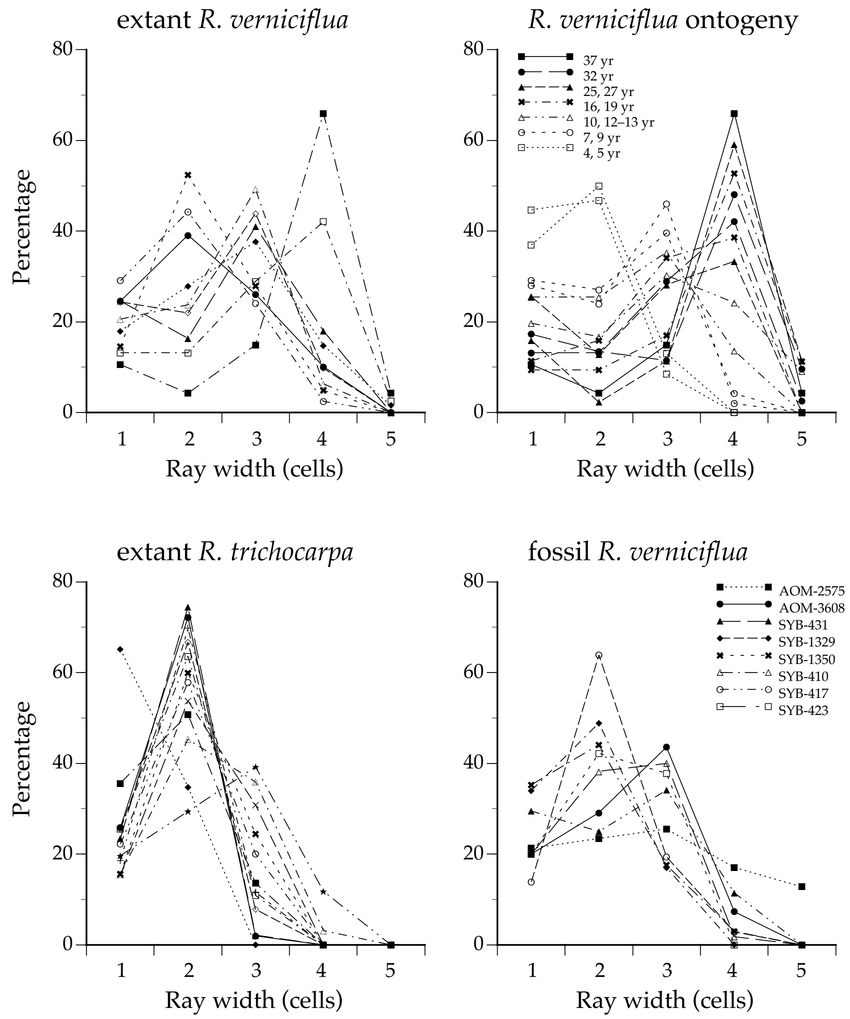


Fig. 17 Ray width in extant *Rhus verniciflua*, two extant *R. verniciflua* specimens for ontogenetic study (TWTw-335, 336), extant *R. trichocarpa*, and fossil *R. verniciflua*. For extant *R. verniciflua* and *R. trichocarpa*, specimen numbers are not given. For ontogenetic trends, ray size was measured in years 4, 9, 12–13, 19, 27, 32, and 37 growth rings for TWTw-335 and in years 4, 7, 10, 16, 25, and 32 growth rings for TWTw-336.

Period found at the Iwatari-kotani 4 Site, Aomori (Fig. 11). These bowls were made from the same tree which was over 26 years old with a reconstructed diameter of 30 cm. At this site, *R. verniciflua* wood was used for bowls and boards and occupied 3% of the total artifacts. At the Shimo-yakebe Site, Tokyo, stakes or planks made of *R. verniciflua* wood were used for wooden remains for water usage of the Late Jomon Period, a wooden track of the Latest Jomon Period, and stakes in a small dam of the Nara to Heian Periods. The stakes of the Nara to Heian Periods were ca. 7 cm in diameter and 12–13 years old. A stake of the Nishi-yoshimi Kodai-doro Ato was split from a 12 year old tree ca. 12 cm in diameter, and a stake at the Sashie B Site was a round wood 3 cm in diameter with traces of lacquer scraping. Thus, besides obtaining lacquer, *R. verniciflua* wood was used for various construction works and making daily utensils in the prehistoric to the ancient periods of Japan. *Rhus verniciflua* trees seem to have had a close relationship with the human life.

In and around the Aomori Plain, *Rhus verniciflua* seems to have been planted commonly in the Early Jomon Period. At Ooyazawa in the center of this plain, dominance of *Castanea* pollen between 3800 and 3100 cal BC of the Early to Middle Jomon Periods was accompanied with the contemporaneous increase of *Rhus* pollen (Goto & Tsuji, 2000). Although traces of human settlement were scarce at Ooyazawa, the dominance of *Castanea* pollen corresponded with the prolific settlement and concomitant dominance of *Castanea* pollen at the Sannai-maruyama Site at the western edge of the plain (Yoshikawa & Tsuji, 1998). Conspicuous usage of *R. verniciflua* wood at the Iwatari-kotani 4 Site beside the Sannai-maruyama Site corresponded with the first settlement of human beings at the Sannai-maruyama Site and indicates that *R. verniciflua* trees were cultivated around these settlements as early as the

Table 2 Archaeological sites that yielded fossil woods of *Rhus verniciflua*

Site Name (Locality)	Age	Specimens (Specimen no.)
Iwatari-kotani 4 Site (Aomori City, Aomori)	Early Jomon	2 vessel-shaped bowls (made from the same tree), 2 bowls (AOM-3608*, 3610, 3054, 3073)
	do.	11 boards, 1 processed wood (AOM-3051, 3069, 3181, 3254, 3256, 3306, 3330, 3334, 3342, 3478, 3111. 3118)
Mukoda 18 Site (Noheji Town, Aomori)	Early Jomon	8 natural woods (AOM-2575*, 2626, 2753, 2754, 2760, 2767, 2768, 2808)
Korekawa-nakai Site (Hachinohe City, Aomori)	Latest Jomon	1 natural wood, 1 processed wood (AOM-2500, 2557)
Shimo-yakebe Site (Higashi-murayama City, Tokyo)	Late Jomon	3 stakes/planks for wooden remains for water usage (SYB-1329*, 1340, 1350*)
	Latest Jomon	1 stake/plank for a wooden track (SYB-431*)
	early 8th–early 10th c. A.D.	9 stakes, 1 processed woods, 1 board (SYB-409, 410*, 411, 412, 414, 415, 417*, 418, 419, 421, 423*)
Nishi-yoshimi Kodai-doro Ato (Yoshimi Machi, Saitama)	Nara to Heian Period	1 stake (beside an ancient public road) (NYII-39)
Sashie B Site (Unoke Machi, Ishikawa)	late 9th–early 10th c. A.D.	1 stake with traces of lacquer scraping (ISF-4679)
Sakuramachi Site (Oyabe City, Toyama)	Edo?	4 stakes with traces of lacquer scraping (TOM-1387, 1388, 1416, 1417)

* specimens used for the quantitative analysis of vessel diameter and ray width.

Early Jomon Period in this plain. Many natural woods of *R. verniciflua* found at the Mukoda 18 Site, Noheji, across a peninsula from the Aomori Plain, also seem to indicate its cultivation around settlements. Through the Jomon Period, cultivation of *R. verniciflua* trees becomes common in northern and central Honshu as shown by fossil woods at the the Korekawa-nakai Site, Aomori, and Shimo-yakebe Site, Tokyo of the Late to Latest Jomon Period.

In the historic periods, cultivation of *R. verniciflua* trees was promoted by the government since the Nara and Heian Periods as an important tax source, and plantation of the trees and production of lacquer ware were prevalent throughout Japan through these periods (Hotta et al., 1989; Amino, 1997, 2000). Fossil woods of *R. verniciflua* of the Nara and Heian Periods are actual proof of such cultivation and popular use of its timber, probably after scraping off of the lacquer.

Prevalence of *R. verniciflua* trees in the Aomori plain of the Early Jomon Period indicates that introduction of the trees and the technique of lacquer processing occurred in periods prior to that, and older records of *R. verniciflua* trees should be sought in Japan, while, on the other hand, clarifying the incipient use of lacquer in China. Based on fossil DNA, it was hypothesized that *R. verniciflua* trees of the Jomon Period differ from those of present China (Iizuka, 2000), but fruit morphology and wood structure do not support this hypothesis. Although fossil records of the Yayoi and Kofun Periods are lacking at present, discovery of *R. verniciflua* woods from several sites in central to northern Honshu has shown a long history of its cultivation in Japan starting at least in the Early Jomon Period.

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