Shuichi Noshiro[1]: Identification of Japanese species of Cupressaceae from wood structure

Abstract Wood anatomical variation of Japanese species of Cupressaceae was studied to evaluate the possibility of identifying the species. Species of Cupressaceae have been important forest resources in Japan since prehistoric periods, and huge quantities of them were transported and used throughout Japan in the early modern Edo period. Thus, species-level identification of species of Cupressaceae is indispensable to clarify prehistoric and historic use of timber in Japan. To evaluate the possibility of distinguishing the species of Cupressaceae, quantitative variation in features of cross-field pitting and rays were studied among seven Japanese species of five genera. Although variation ranges overlapped considerably, size, type, and frequency of cross-field pitting allowed identification of these species if individual averages were compared. Ray height and frequency, which are highly affected by the level of cambial activity, mostly overlapped among the studied species and could not be used for identification. This study confirmed the possibility of distinguishing the species by traditional criteria, but also revealed new criteria to be considered in future identification.

Key words: cross-field pits, Cupressaceae, Japan, ray height, wood structure

Introduction

Species of Cupressaceae (including former Taxodiaceae) have been important forest resources in Japan since prehistoric periods. Even in the early Jomon period, beginning at ca. 6300 B.P. (ca. 5300 cal B.C.), when timber selection and extensive tool making seem to have started, various species of Cupressaceae were used for tools, boards, and stakes (e.g., Noshiro et al., 1996; Noshiro & Suzuki, 2006). In the ancient period, huge amounts of Cupressaceae trees together with *Sciadopitys verticillata* (Thunb.) Siebold et Zucc. (Sciadopityaceae) were used for the construction of palaces and surrounding cities in the Kinki district (Yamada, 1993). In the early modern Edo period starting from 1600 A.D., virgin forests were more or less felled throughout Japan, and huge quantities of timber were transported and used especially in urban areas (e.g., Suzuki & Noshiro, 2004, 2006, 2008). Species of Cupressaceae were valued for their straight grains and durability, and most of the virgin resources were depleted by the end of 17th century (Tokoro, 1980). Thus, species-level identification of species of Cupressaceae is indispensable to clarify prehistoric and historic use of timber in Japan, but, so far, the possibility of distinguishing species from wood structure has not been evaluated critically.

There is a long history of the anatomical study of wood structure of Japanese species of Cupressaceae (Fujioka, 1913; Iwaki, 1918a, 1918b; Kanehira, 1921, 1926; Iwata & Kusaka, 1952; Kobayashi, 1957; Shimaji & Ito, 1982), but criteria for the identification of Japanese species were not established when large amounts of archaeological woods came to be recovered in 1980s. Previous studies relied on inconsistent features such as transition from early- to latewood, distribution of axial parenchyma in cross sections, nodules on horizontal walls of axial parenchyma cells, nodules on vertical walls of ray parenchyma cells, occurrence of indentures, and shape of ray cells in tangential sections. Expression of these features change greatly depending on the growth and age of individuals and were found to be inapplicable to species-level identification (e.g., Miyoshi & Shimakura, 1933). This is probably because extensive collection and preparation of materials were difficult when these studies were carried out. Among the features used by these authors, cross-field pitting seemed to be most promising and has been used for the identification since 1980s, but the variation range of cross-field pitting within species has never been studied. Besides cross-field pitting, some of the above studies and another one on species-level variation of two *Chamaecyparis* species (Miyoshi & Shimakura, 1934) indicated that there might be species differences in ray height and frequency. On the other hand, some ray features in conifers such as ray height and number of ray cells were known to be affected by

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the level of cambial activity (Miyoshi & Shimakura, 1934; Gregory & Romberger, 1975).

Thus, to statistically evaluate the criteria used for the identification of Japanese species of Cupressaceae since the 1980's, species-level variation in cross-field pitting and ray features were studied using specimens collected from mature trees throughout Japan.

Material and methods

Seven tree species in five genera of Cupressaceae that grow commonly in Japan were studied (Table 1). The study was based on 14 specimens of *Chamaecyparis obtusa* (Siebold et Zucc.) Endl., nine specimens of *Chamaecyparis pisifera* (Siebold et Zucc.) Endl., three specimens of *Juniperus chinensis* L., six specimens of *Juniperus rigida* Siebold et Zucc., eight specimens of *Thuja standishii* (Gordon) Carrière, 11 specimens of *Thujopsis dolabrata* (L. f.) Siebold et Zucc., and 11 specimens of *Cryptomeria japonica* (L. f.) D. Don. All the wood specimens were from mature trees. Specimens without a record of tree size were commercial timber or materials through forest offices. Preparations of specimens deposited at the xylarium of the Forestry and Forest Products Research Institute, Tsukuba, Japan (TWTw) were made by conventional methods using sledge microtomes, stained with Safranin O and Gentian Violet, dehydrated through an alcohol series, and mounted with Canada Balsam. Beside these, seven preparations were donated from other institutes.

We studied size, frequency, type of cross-field pits and height and frequency of rays against growth ring width. Features of cross-field pits were averaged from 50 counts obtained from three images of 225 × 169 μm in the earlywood of a radial section. Cross-field pit border diameter was measured horizontally, using a video micrometer (BX41N-32/XD200, Olympus Co., Tokyo, Japan). Cross-field pit number was averaged from counts in 50 cross-fields excluding cross-fields in marginal rows and those without pits. Cross-field pit type was determined following the IAWA list of microscopic features for softwood identification (Richter et al., 2004). Features of rays were obtained from two images of 3390 × 2700 μm of a tangential section. Ray height was averaged from 50 counts from the two images, and ray frequency was calculated from the total ray number in the two images. Average growth ring width was calculated from the radial length of cross sections.

Results

All the features of cross-field pitting overlapped considerably, and it was impossible to distinguish species using just one feature (Table 2). By combining several features, however, most species could be separated.

Chamaecyparis obtusa had piceoid to cupressoid pits about 5–6.5 μm in diameter with circular borders that occurred 1–2 per cross-field (Figs. 1a–1d, 3). Cross-field pits usually occurred in the vertical center of cross-fields. The apertures of cross-field pits usually opened diagonally to vertically, but in a rare specimen almost horizontally with elliptic borders (TWTw-22026, Fig. 1d). The variation of average pit size was confined within 1 μm from 5.5 to 6.5 μm (Table 2).

Chamaecyparis pisifera had cupressoid-taxodioid pits 6–8 μm in diameter with elliptic borders that occurred 1–2 per cross-field (Figs. 1e–1h, 3). Cross-field pits usually occurred in the vertical center of cross-fields. The apertures of cross-field pits usually opened diagonally to horizontally. In one specimen (TWTw-874, Fig. 1e) cross-field pits were piceoid to cupressoid. In another specimen (TWTw-24196, Fig. 1h) cross-field pits were less than 5 μm in diameter with circular borders.

Juniperus chinensis had piceoid (SN-4935, Fig. 1j) to cupressoid (TWTw-36, Fig. 1i) pits 7 μm in diameter with circular borders that often occurred 1–2 per cross-field (Fig. 3). Cross-field pits occupied various places in cross-fields. The apertures of cross-field pits opened variously from horizontally to vertically.

Juniperus rigida had cupressoid-taxodioid pits 7–9 μm in diameter with circular borders that often occurred 1–2 per cross-field (Figs. 1k–1l, 3). Cross-field pits occupied various places in cross-fields. The apertures of cross-field pits opened variously from horizontally to vertically.

Thuja standishii had distinctly taxodioid pits 5–7 μm in diameter with elliptic borders that occurred more than two (up to five) per cross-field (Figs. 1m–1p, 3). Cross-field pits occupied various places in cross-fields. The apertures of cross-field pits usually opened horizontally.

Thujopsis dolabrata had small cupressoid to taxodioid pits less than 5.5 μm in diameter with circular borders that occurred 1–2 (occsionally up to 4) per cross-field (Figs. 2a–2d, 3). Cross-field pits occupied various places in cross-fields. The apertures of cross-field pits usually opened diagonally to vertically, but occasionally did diagonally to horizontally.

Cryptomeria japonica had distinctly taxodioid pits more than 7 μm in diameter with circular to elliptic borders that usually occurred two per cross-field (Figs. 2e–2h, 3). Cross-field pits usually occurred in the vertical center of cross-fields. The apertures of cross-field pits usually opened diagonally to horizontally. One specimen from an alpine scrub (TWTw-9289) com-

Table 1 List of specimens of Cupressaceae used for the study

Specimen No.	Locality	Tree size
Chamaecyparis obtusa (Siebold et Zucc.) Endl.		
TWTw-609	Tokyo Univ. Forest, Ootaki mura, Chichibu Gun, Saitama Pref.	—
TWTw-652	Ohtaki, Kiso gun, Nagano Pref.	—
TWTw-3329	Tokyo Univ. Forest, Amatsu, Chiba Pref.	—
TWTw-9293	Ogawa, Agematsu cho, Nishi-chikuma gun, Nagano Pref.	H = 26 m, DBH = 38–63 cm
TWTw-18791	Takaoka cho, Higashi-morokata gun, Miyazaki Pref.	H = 9 m, DBH = 21 cm
TWTw-19113	Oogou-dani, Kawauchi, Miyama cho, Kita-muro gun, Mie Pref.	H = 11 m, DBH = 28 cm
TWTw-20279	Higashi-mata-dani,Nishi River, Umaji mura, Aki gun, Kochi Pref.	H = 15.5 m, DBH = 37 cm
TWTw-21376	Tochizu, Tateyama machi, Naka-niikawa gun, Toyama Pref.	H = 22 m, DBH = 32 cm
TWTw-21542	Sambe Univ. Forest, Tsunoi, Iinan cho, Iishi gun, Shimane Pref.	H = 11 m, DBH = 17 cm
TWTw-22026	Mt. Washi-ga-take, Oowashi,Takasu cho, Gujo city, Gifu Pref.	H = 8 m, DBH = 23 cm
TWTw-24303	Kiso River, Kiso mura, Kiso gun, Nagano Pref.	H = 14 m, DBH = 52 cm
TWTw-24715	Ogawa, Sekimoto cho, Kita-ibaraki city, Ibaraki Pref.	H = 17.5 m, DBH = 32 cm
TWTw-24841	Yokokawame, Waga cho, Kitakami city, Iwate Pref.	H = 19 m, DBH = 45 cm
s. n.	Yaku Is., Kagoshima Pref.	—
Chamaecyparis pisifera (Siebold et Zucc.) Endl.		
TWTw-651	Ohtaki, Kiso gun, Nagano Pref.	—
TWTw-874	Kiso, Nagano Pref.	—
TWTw-9294	Ogawa, Agematsu cho, Nishi-chikuma gun, Nagano Pref.	H = 31 m, DBH = 73 cm
TWTw-18727	Mt. Kushigata, Minami-koma gun, Yamanashi Pref.	H = 12 m, DBH = 31 cm
TWTw-24196	Ugui River, Outaki mura, Kiso gun, Nagano Pref.	H = 9 m, DBH = 17 cm
TWTw-24266	Shiratani River, Outaki mura, Kiso gun, Nagano Pref.	fallen tree; H = – m, D = 80 cm
TWTw-24293	Kiso River, Kiso mura, Kiso gun, Nagano Pref.	H = 10.5 m, DBH = 19 cm
SN-4913	Ookawa R. at W foot Mts. Nasu, Kuroiso city, Tochigi Pref.	H = 10 m, D = 30 cm
SN-4921	Ookawa R. at W foot Mts. Nasu, Kuroiso city, Tochigi Pref.	H = 22 m, D = 60 cm
Juniperus chinensis L.		
TWTw-36	FFPRI, Meguro, Tokyo	—
TWTw-6322	Asakawa Experimental Forest, Hachioji city, Tokyo	—
SN-4935	Yawatano to Jogasaki-kaigan, Ito city, Shizuoka Pref.	H = 8 m, DBH = 30 cm
Juniperus rigida Siebold et Zucc.		
TWTw-950	Tokyo Univ. Forest, Chichibu Gun, Saitama Pref.	—
TWTw-1204	Foot of Mt. Fuji, Yamanashi Pref.	—
TWTw-6354	Asakawa Experimental Forest, Hachioji city, Tokyo	—
TWTw-19706	Aneyoshi to Todo-ga-saki, Omoe, Miyako city, Iwate Pref.	H = 4 m, DBH = 10 cm
TWTw-19943	Tozawa, Kawai R., Horai cho, Minami-shitara gun, Aichi Pref.	H = 4 m, DBH = 10.5 cm
TWTw-22824	Samjeong-ri san, Machon-myun, Hamyang-gun, Gyeongnam, Korea	H= 9 m, DBH = 17 cm
Thuja standishii (Gordon) Carrière		
TWTw-649	Ohtaki, Kiso gun, Nagano Pref.	—
TWTw-875	Kiso, Nagano Pref.	—
TWTw-18113	Tashiro For. Road, Kuriyama mura, Shioya gun, Tochigi Pref.	H = 18 m, DBH = 103 cm
TWTw-21316	Arimine, Ooyama machi, Kami-niikawa gun, Toyama Pref.	H = 17 m, DBH = 70 cm
TWTw-21409	Arimine, Ooyama machi, Kami-niikawa gun, Toyama Pref.	H = 18 m, DBH = 103 cm
TWTw-22003	Mt. Washi-ga-take, Oowashi, Takasu cho, Gujo city, Gifu Pref.	stem mostly dead; H = 6.5 m, DBH = 43 cm
TWTw-24337	Kuro-sawa River, Agematsu machi, Kiso gun, Nagano Pref.	H = 14 m, DBH = 30 cm
Kan-25		
Thujopsis dolabrata (L. f.) Siebold et Zucc.		
var. *dolabrata*		
TWTw-3331	Tokyo Univ. Forest, Amatsu, Chiba Pref.	—
TWTw-18162	Koza-ike Zawa, Kuriyama Mmura, Shioya gun, Tochigi Pref.	H = 12 m, DBH = 38 cm
TWTw-24322	Kuro-sawa River, Agematsu machi, Kiso gun, Nagano Pref.	H = 7 m, DBH = 19 cm
TWTw-24340	Kuro-sawa River, Agematsu machi, Kiso gun, Nagano Pref.	H = 17.5 m, DBH = 66 cm
Kan-9361	Sumiyoshi cho, Kanazawa city, Ishikawa Pref.	—
Kan-9362	Sumiyoshi cho, Kanazawa city, Ishikawa Pref.	—
var. *hondae* Makino		
TWTw-1300	Shiura Forest Office, Tsugaru, Aomori Pref.	—
TWTw-7200	Aomori Pref.	—
TWTw-9296	Nishi, Takisawa, Aomori city, Aomori Pref.	H = 20 m, DBH = 32–55 cm
TWTw-24875	Sawauchi-maego, Nishi-waga machi, Waga gun, Iwate Pref.	H = 11 m, DBH = 19.5 cm
TWTw-25023	Kami-naka-no-sawa River, Kaminokuni cho, Hiyama, Hokkaido	H = 10 m, DHB = 20 cm
Cryptomeria japonica (L. f.) D. Don		
TWTw-817	Yamase Forest Office, Akita Pref.	—
TWTw-6698	Mt. Hakusan, Ishikawa Pref.	— (native tree)
TWTw-7992	Yakushima Is., Kagoshima Pref.	— (tree felled in Edo period)
TWTw-9092	Akita Pref.	— (commercial timber)
TWTw-9289	Tanabe, Takajo cho, Kita-morogata gun, Miyazaki Pref.	H = 19 m, DBH = 19–37 cm
TWTw-9290	Funaoka, Kyowa cho, Senboku gun, Akita Pref.	H = 24 m, DBH = 20–48 cm
TWTw-9291	Sejiri, Tatsuta mura, Iwata gun, Shizuoka Pref.	H = 25 m, DBH = 15–52 cm
TWTw-16040	Mt. Kuromi, Kami-yaku cho, Kumage gun, Kagoshima Pref.	H = 2.5 m, DBH = 35 m (in alpine scrub)
TWTw-19115	Oogou-dani, Kawauchi, Miyama cho, Kita-muro gun, Mie Pref.	H = 14 m, DBH = 43 cm
TWTw-20265	Mt. Senbon-yama, Nishi River, Umaji mura, Aki gun, Kochi Pref.	H = 13 m, DBH = 47 cm
TWTw-21384	Zashubou, Tateyama machi, Naka-niikawa gun, Toyama Pref.	H = 22 m, DBH = 46c m

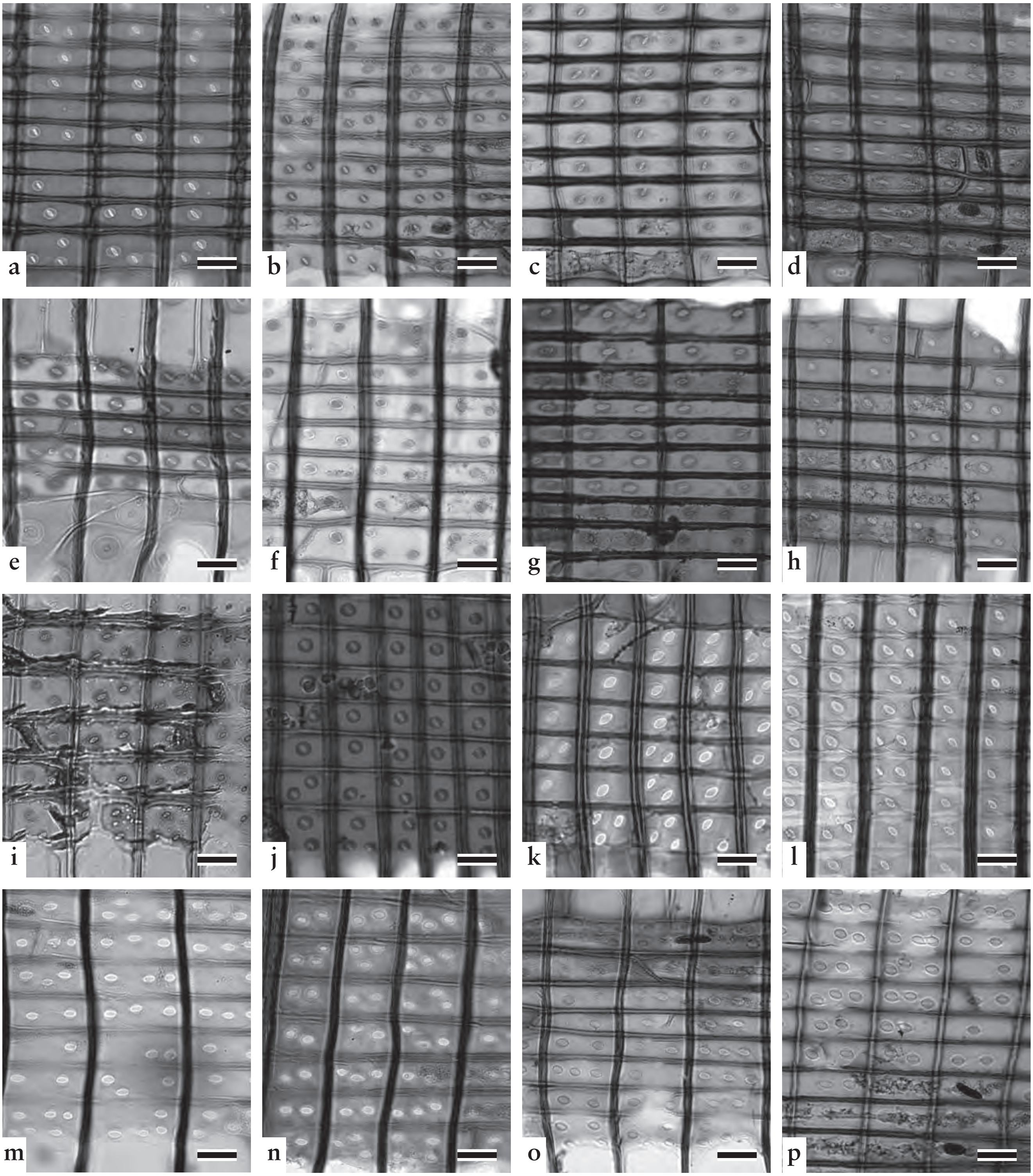

Fig. 1 Cross-field pits of Japanese species of Cupressaceae (1). — a–d: *Chamaecyparis obtusa* (Siebold et Zucc.) Endl. (a: TWTw-21542, b: TWTw-24303, c: TWTw-24841, d: TWTw-22026). – e–h: *Chamaecyparis pisifera* (Siebold et Zucc.) Endl. (e: TWTw-874, f: TWTw-18727, g: TWTw-24266, h: TWTw-24196). – i–j: *Juniperus chinensis* L. (i: TWTw-36, j: SN-4935). – k–l: *Juniperus rigida* Siebold et Zucc. (k: TWTw-19706, l: TWTw-19943). – m–p: *Thuja standishii* (Gordon) Carrière (m: TWTw-21316, n: TWTw-21409, o: TWTw-22003, p: TWTw-24337). – Scale = 20 µm.

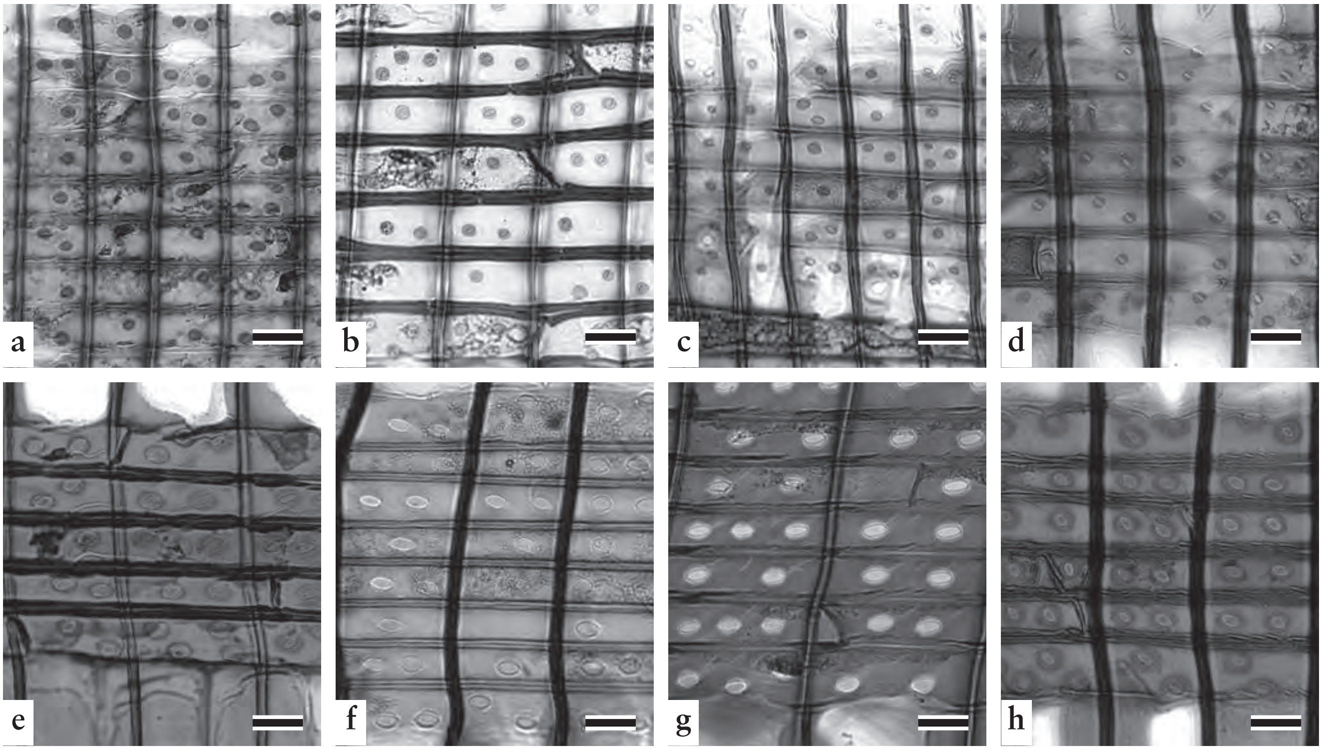

Fig. 2 Cross-field pits of Japanese species of Cupressaceae (2). — a–d: *Thujopsis dolabrata* (L. f.) Siebold et Zucc. (a: TWTw-9296, b: TWTw-18162, c: TWTw-24875, d: TWTw-25023). – e–h: *Cryptomeria japonica* (L. f.) D. Don (e: TWTw-817, f: TWTw-20265, g: TWTw-21384, h: TWTw-9289). – Scale = 20 µm.

Table 2 Range of specimen averages and original counts (in parentheses) of the features of cross-field pits and rays among Japanese species of Cupressaceae.

Species	Pit size (µm)		Pit number (no./cross-field)		Pit type			Ray height (cells)	Ray frequency (no./mm2)
					piceoid	cupressoid	taxodioid		
Chamaecyparis obtusa	5.1–6.5	(3.5–8.6)	1.3–2	(1–3)	64% (20–96)	32% (4–70)	3% (0–12)	3.3–7.9 (1–31)	43.6–61.8
Chamaecyparis pisifera	5.7–7.8	(2.9–9.7)	1.2–1.9	(1–3)	4% (0–18)	38% (2–80)	58% (2–98)	3.3–5.7 (1–14)	41.9–77.1
Juniperus chinensis	6.6–7.2	(4.8–9.9	1.2–2.3	(1–4)	28% (2–62)	45% (38–54)	27% (0–44)	4.3–6.9 (1–21)	32.2–68.8
Juniperus rigida	7.4–9.0	(4.8–11.4)	1.2–1.7	(1–4)	1% (0–4)	20% (2–46)	78% (50–98)	2.6–6.4 (1–18)	43.9–85.4
Thuja standishii	5.4–6.8	(4.2–8.6)	1.8–2.6	(1–5)	0% (0–2)	4% (0–20)	96% (78–100)	2.9–7.2 (1–23)	48.9–83.1
Thujopsis dolabrata	4.3–5.8	(3.1–7.5)	1.3–2	(1–4)	9% (0–26)	26% (6–60)	66% (20–94)	3.3–5.6 (1–44)	39.2–66.8
Cryptomeria japonica	7.3–10.1	(5.5–12.5)	1.3–2.1	(1–3)	0% (0–0)	3% (0–8)	97% (92–100)	3.5–6.4 (1–15)	28.9–58.2

monly had taxodioid to cupressoid pits with diagonal to vertical apertures, but also had taxodioid pits with diagonal to horizontal apertures (Fig. 2h).

Height and frequency of rays were mostly overlapped, and species could not be distinguished using these features (Table 2; Fig. 4). Ray height had a positive correlation with growth ring width, but ray frequency did not have any correlation with it. Between two species of *Chamaecyparis*, ray height differed significantly (5% level by t-test) and varied twice as much in *Chamaecyparis obtusa* than in *Chamaecyparis pisifera*, but a quite opposite trend occurred in ray frequency. *Cryptomeria japonica* had a significantly lower ray frequency than the other species (0.5% level by t-test), but more than half of its range overlapped with ranges of the other species.

Discussion

1. Identification of species by cross-field pitting

Combination of pit size, pit number per cross-field,

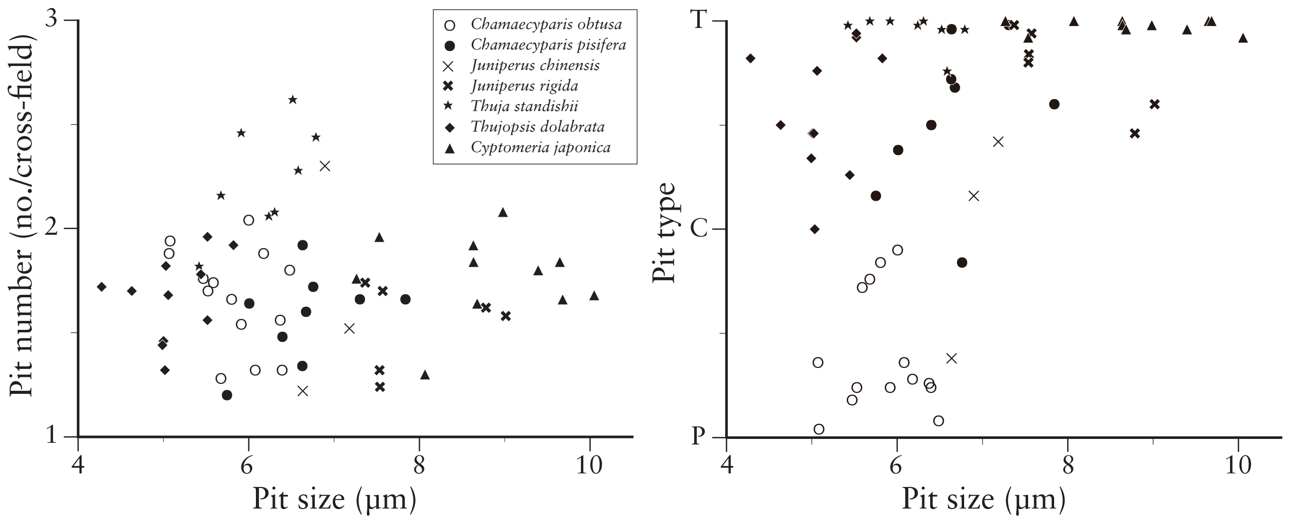

Fig. 3 Cross-field pit number and type against size among Japanese species of Cupressaceae.

and pit type of cross-field pitting proved to be a reliable criterion for the identification of Japanese species of Cupressaceae. Although there was much overlap in the ranges of these features, if individual averages were compared, most species could be distinguished. Previous studies on the wood structure of Japanese conifers did not evaluate critically the variation in cross-field pitting within and among individuals, and keys tended to show narrow fixed ranges for critical features, probably obtained from observations of a limited number of specimens. Pit type for most species, for example, was described as cupressoid or taxodioid (e.g., Kobayashi, 1957; Shimaji & Ito, 1982), but, in the present study, pit type was found to vary from piceoid to cupressoid in *Chamaecyparis obtusa* and from cupressoid to taxodioid in *Chamaecyparis pisifera* and *Thujopsis dolabrata*. Pit number for *Cryptomeria japonica* and *Chamaecyparis* was previously described as two and that for others as three or more (Shimaji & Ito, 1982), but pit number averaged between one to two in all the studied species except for *Thuja standishii*. Thus, observation of ranges of pit features and obtaining their averages are vital in the identification of Japanese species of Cupressaceae.

Specific difference in the formation of cross-field pits are not known. Among the features of cross-field pitting, the orientation of pit apertures, especially in latewood, is known to follow the orientation of microfibrils (Donaldson, 2008). In *Picea abies* L., the orientation of pit apertures in the latewood had a good correlation with microfibril angles, but that this did not apply to the earlywood cells (Lichtenegger et al., 2003). Lichtenegger et al. (2003) considered that the discrepancies in the earlywood were derived from averaging between the microfibril angles of thin-walled earlywood tracheids and the microfibril angles of ray parenchyma cells. Little is known about the control or development of cross-field pitting such as size, number, and opening, or their correlation with other features, but the results of the present study show that all these aspects are somehow controlled at the species-level among the studied species.

2. Ray features and species identification

Rays in conifers are known to vary in proportion to the level of cambial activity. In *Picea glauca* and *Abies balsamea*, Gregory & Romberger (1975) showed that number of ray cells per square millimeter and ray height were positively correlated with growth ring width, whereas ray frequency was nearly constant irrespective of growth ring width. In two Japanese species of *Chamaecyparis*, Miyoshi & Shimakura (1934) showed that ray height was positively correlated with growth ring width and that *C. obtusa* tended to have taller rays than *C. pisifera* irrespective of growth ring width. Ray frequency of these two species did not have any correlation with growth ring width, but *C. pisifera* tended to have more rays than *C. obtusa*. Thus, although ray height is clearly affected by the level of cambial activity and ray frequency is not, ray height and ray frequency has different averages in these species. The present study confirmed the trends found

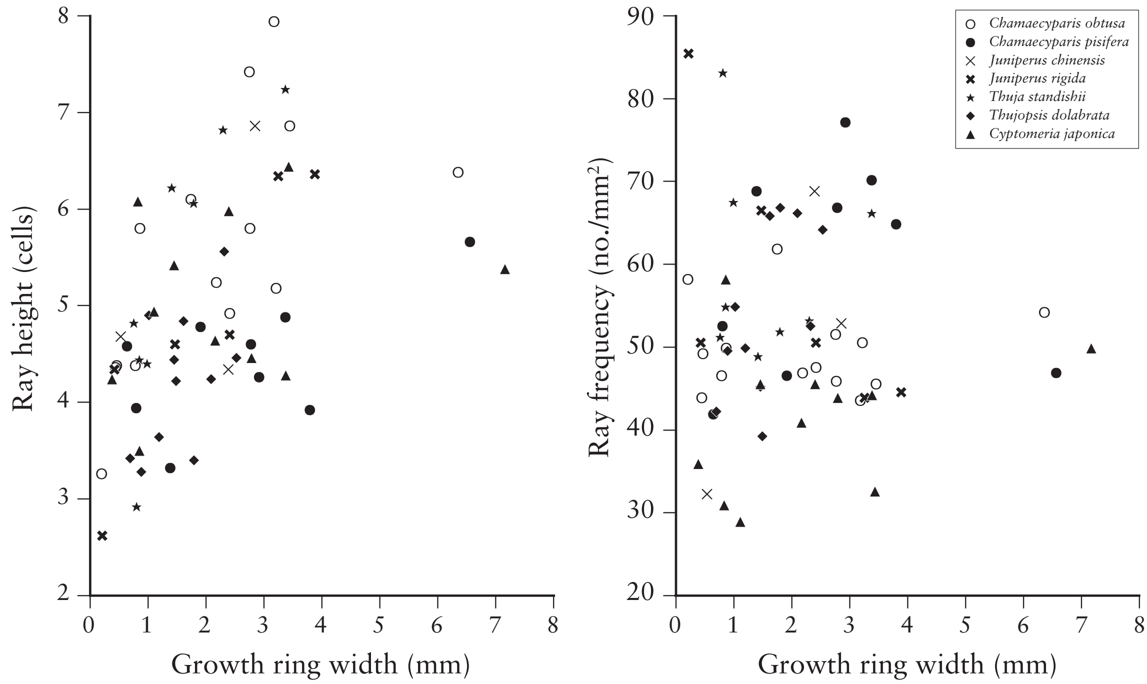

Fig. 4 Ray height and frequency against growth ring width among Japanese species of Cupressaceae.

by Miyoshi & Shimakura (1934), as *Chamaecyparis obtusa* tended to have taller, but sparser rays than *C. pisifera* (Fig. 4). Among other species, *Thuja standishii* had distinctly steeper increase in ray height with growth ring width, and denser rays than *Cryptomeria japonica*. However, as pointed out by Miyoshi & Shimakura (1934), the ranges of species values had considerable overlaps, and it is not feasible to use ray features as criteria for the identification of the studied species.

Acknowledgements

This study was partly supported by the Grant-in-Aid from the Ministry of Education, Culture, Sports, Science and Technology, Government of Japan (No. 21300332).

References

Donaldson, L. 2008. Microfibril angle: Measuremeent, variation and relationships—a review. *IAWA Journal* **29**: 345–386.

Fujioka, M. 1913. Stüdien über den anatomischen Bau des Holzes der japanischen Nadelbäume. *Journal of the College of Agriculture, Imperial University of Tokyo* **4**: 201–236, pl. 18–26.

Gregory, R. A. & Romberger, J. A. 1975. Cambial activity and height of uniseriate vascular rays in conifers. *Botanical Gazette* **136**: 246–253.

Iwaki, T., 1918a. Microscopical distinction of some Japanese coniferous wood (1). *Botanical Magazine (Tokyo)* **32**: 187–198 (in Japanese).

Iwaki, T., 1918b. Microscopical distinction of some Japanese coniferous wood (2). *Botanical Magazine (Tokyo)* **32**: 219–237 (in Japanese).

Iwata, T. & Kusaka, M. 1952. *Coniferae Japonicae Illustratae*. Sangyo-tosho Co. Ltd., Tokyo (in Japanese).

Kanehira, R. 1921. *Identification of the Important Japanese Woods by Anatomical Characters*. Bureau of Productive Industries, Government of Formosa, Taihoku.

Kanehira, R. 1926. *Anatomical Characters and Identification of the Important Woods of the Japanese Empire*. Department of Forestry, Government Research Institute, Taihoku (in Japanese).

Kobayashi, Y. 1957. A card sorting system for the identification of softwood in Japan. *Bulletin of the Government Forest Experiment Station* No. 98: 1–84, pl.1–16 (in Japanese).

Lichtenegger, H. C., Müller, M., Wimmer, R., & Fratzl, P. 2003. Microfibril angles inside and outside crossfields of Norway spruce tracheids. *Holzforschung* **57**: 13–20.

Miyoshi, T. & Shimakura, M. 1933. On the wood structure between *Chamaecyparis obtusa*. *Journal of the Japanese*

Forestry Society **15**: 894–904 (in Japanese).
Miyoshi, T. & Shimakura, M. 1934. Comparison of the wood structure between *Chamaecyparis obtusa* and *C. pisifera*. *Journal of the Japanese Forestry Society* **16**: 552–561 (in Japanese).
Noshiro, S. & Suzuki, M. 2006. Utilization of forest resources in the early Jomon period at and around the Sannai–maruyama site in Aomori Prefecture, northern Japan. *Japanese Journal of Historical Botany*, Special Issue No. 2: 83–100.
Noshiro, S., Suzuki, M. & Amitani, K. 1996. Species selection for wooden artifacts recovered from the Torihama shell midden. *Torihama Shell Midden Research* No. 1: 23–79 (in Japanese).
Richter, H. G., Grosser, D., Heinz, I. & Gasson, P., eds. 2004. IAWA list of microscopic features for softwood identification. *IAWA Journal* **25**: 1–70.
Shimaji, K. & Ito, T. 1982. Atlas of Wood Structure of Japanese Trees. Chikyu-sha, Tokyo (in Japanese).
Suzuki, S. & Noshiro, S. 2004. Forms and materials of wooden coffins of the Edo period recovered from Hatchobori 3-chome site, Chuo-ku, Tokyo. *Japanese Journal of Historical Botany* **12**: 75–86 (in Japanese).
Suzuki, S. & Noshiro, S. 2006. Materials and forms of wooden coffins of the Edo period excavated from the Sugen-ji and Shoken-ji sites, Shinjuku, Tokyo. *Japanese Journal of Historical Botany* **14**: 61–72 (in Japanese).
Suzuki, S. & Noshiro, S. 2008. Transition in construction timber usage and its social background in the early modern Edo period deduced from wooden remains excavated from the Nihonbashi 1-chome site, Chuo-ku, Tokyo. *Japanese Journal of Historical Botany* **16**: 57–72 (in Japanese).
Tokoro, M. 1980. *History of Forestry in the Early Modern Japan*. Yoshikawa-kobunkan, Tokyo (in Japanese).
Yamada, M. 1993. Compilation of literature on archaeological wooden remains in Japan—History of human-plant relationship from the point of timber economy and species selection. *Japanese Journal of Historical Botany,* Special Issue No. 3: 1–242 (in Japanese).

(Accepted: 22 Dec. 2010)