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Tabularia kobayasii: a new araphid diatom (Bacillariophyta, Fragilariaceae) from Japan

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Abstract

A new species of *Tabularia*, *T. kobayasii*, was found on seaweeds collected from several estuaries in the Central Pacific coast of Japan. Its morphology was examined by light and scanning electron microscopy; details are described herein. This araphid diatom is characterized by: 1) tufted or band-like colony; 2) valves lanceolate, flat with steep mantle, striae consisting of cribrate areolae, a wide lanceolate sternum, single rimoportula, and an occelulimbus at both poles; and 3) a cingulum consisting of a few non-fimbriated girdle bands including the valvocopula.

Key Words: araphid diatom, Bacillariophyta, estuary, Japan, new species, *Tabularia kobayasii*

Introduction

Tabularia Williams & Round (1986: 320) (Bacillariophyta, Fragilariaceae) is one of the commonest marine '*Synedra*' *sensu lato* forms. Its species are usually epiphytic or epilithic and attached to substrata by mucilage pads, usually in tufts. Fourteen species are listed in Algaebase (Guriry & Guiry 2015). *Tabularia* differs from the other similar genera, such as *Hyalosynedra* Williams & Round (1986: 318) and *Neosynedra* Williams & Round (1986: 332), by virture of the structure of the vela and presence of an ocellulimbus. In addition, because of the fine structure of the striae, Williams & Round (1986) informally subdivided the genus into the following three groups: i) those with valves having biseriate striae with simple closing plates; ii) those with valves having cribra with heavily silicified cross-members; and iii) those with valves having a complex cribrate closing plate.

In this study, an unrecognized species of *Tabularia*, belonging to the second group, was found growing on seaweeds (e.g. *Caloglossa ogasawaraensis* Okamura (1897: 13)) from several estuaries in the Central Pacific coast of Japan. It is described using light (LM) and scanning electron microscopy (SEM) and comparisons are made to similar taxa. It has been named *Tabularia kobayasii* Hidek. Suzuki & Mitsuishi *sp. nov*.

Material and methods

Samples were obtained from seaweeds collected from several estuaries in the Central Pacific coast of Japan as listed in Table 1. Samples and type slides were deposited at the Natural History Museum (BM 101792), the Museum of Fishery Sciences, Tokyo University of Marine Science and Technology, Japan (MTUF-AL 43058–43077), and the Micropaleontology Collection, National Museum of Nature and Science, Tokyo (MPC-RM-HK 4711 and 4718).

Samples were fixed with 2.5% glutaraldehyde or 10% formalin solution. The material was treated using the bleaching method as described by Nagumo & Kobayasi (1990), Nagumo (1995) and Osada & Nagumo (2001). Light and scanning electron microscopy techniques are described in Kuriyama *et al*. (2010). Prepared specimens were examined using HITACHI S-5000 SEM (The Nippon Dental University School of Life Dentistry at Tokyo).

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TABLE 1. List of samples used in this study.

No.	Substrate	Estuary	Site	Latitude	Longitude	Date	Collector	Material and slide Number
I	*Caloglossa ogasawaraensis*	Naka River	Isohamacho, Oarai-machi, Higashiibaraki-gun, Ibaraki Pref.	36˚ 20' N	140˚ 35' E	31 Jul. 2008	K. Mitsuishi	MTUF-AL 43058
						30 Oct. 2008	K. Mitsuishi	MTUF-AL 43059
II	n.d.	Arakawa River	Kasai bridge, Nishikasai, Edogawa-ku, Tokyo	35˚ 39' N	139˚ 50' E	Aug. 1994	H. Kobayasi	MPC-RM-HK 4711
III	n.d.	Sumida River	Ryogoku, Sumida-ku, Tokyo	35˚ 41' N	139˚ 47' E	undated 1994	H. Kobayasi	MPC-RM-HK 4718
IV	*Caloglossa ogasawaraensis*	Meguro River	Keihin Canal, Konan, Minato-ku, Tokyo	35˚ 37' N	139˚ 45' E	18 Jun. 2008	K. Mitsuishi	MTUF-AL 43060
						16 Jul. 2008	K. Mitsuishi	MTUF-AL 43061
						3 Aug. 2008	K. Mitsuishi	BM 101792 and MTUF-AL 43062
						3 Sep. 2008	K. Mitsuishi	MTUF-AL 43063
						13 Oct. 2008	K. Mitsuishi	MTUF-AL 43064
						12 Nov. 2008	K. Mitsuishi	MTUF-AL 43065
						13 Dec. 2008	K. Mitsuishi	MTUF-AL 43066
						28 Mar. 2009	K. Mitsuishi	MTUF-AL 43067
						24 Apr. 2009	K. Mitsuishi	MTUF-AL 43068
						24 May 2009	K. Mitsuishi	MTUF-AL 43069
V	*Caloglossa ogasawaraensis*	Tsurumi River	Namamugi, Tsurumi-ku, Yokohama-shi, Kanagawa Pref.	35˚ 29' N	139˚ 40' E	4 Aug. 2008	K. Mitsuishi	MTUF-AL 43070
						27 Oct. 2008	K. Mitsuishi	MTUF-AL 43071
						10 Feb. 2009	K. Mitsuishi	MTUF-AL 43072
						25 May 2009	K. Mitsuishi	MTUF-AL 43073
VI	*Caloglossa ogasawaraensis*	Matsukoshi River	Nagasaka, Yokosuka-shi, Kanagawa Pref.	35˚ 13' N	139˚ 37' E	2 Sep. 2008	K. Mitsuishi	MTUF-AL 43074
VII	*Cladophora* sp.	Ota River	Kumomi, Matsuzaki-machi, Kamo-gun, Shizuoka Pref.	34˚ 43' N	138˚ 44' E	13 May 2001	H. Suzuki	MTUF-AL 43075
						23 Nov. 2008	H. Suzuki	MTUF-AL 43076
VIII	*Caloglossa ogasawaraensis*	Kuroishi River	Kogawa, Yaizu-shi, Shizuoka Pref.	34˚ 50' N	138˚ 19' E	16 Jun. 2009	H. Suzuki	MTUF-AL 43077

The valves' size and striae density were determined from measurements of 30 valves. For morphometric analysis, all scanning electron micrographs were taken under identical conditions to exclude potential mechanical errors being involved in SEM (with an accelerating voltage = 2 kV, magnification = 15,000–20,000). Measurements were made on 20 valves that were randomly selected from the type material under SEM. The measured variables were a) length of the minor axis of areola (= length of vimines) of the middle of each valve, which are cross connections of virgae forming areolae; and b) length of the major axis of ocellulimbus.

The temperature and salinity from the sampling sites were measured with a bar thermometer and a hand-held refractometer (IS/Mill-E, ATAGO Co., Ltd, Tokyo, Japan), respectively.

Terminology for the parts of the valve and girdle follow Anonymous (1975), Ross *et al.* (1979) and Cox & Ross (1981), with additional terms from Kobayasi *et al.* (2006).

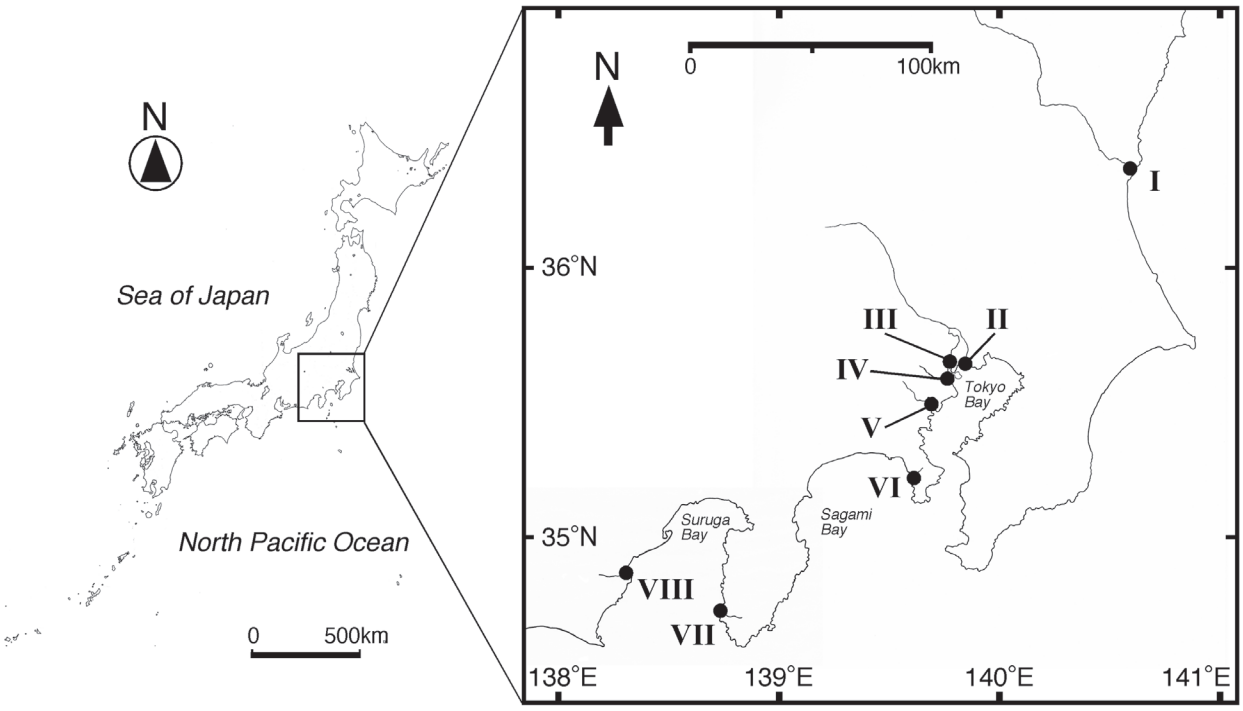


FIGURE 1. Map of the 8 sampling estuaries in the Central Pacific coast of Japan. Numbers (I–VIII) correspond to those in Table 1.

New species description

Division Bacillariophyta

Class Bacillariophyceae

Order Fragilariales

Family Fragilariaceae

Genus *Tabularia*

Tabularia kobayasii Hidek. Suzuki & Mitsuishi *sp. nov*. (Figs 2–32)

Cells needle-like, grow either solitary or in tufted or band-like colonies attached to substrate by mucilage pads (Figs 2, 4, 5); valves only rarely joined face-to-face (Fig. 3). Each cell with several plate-like chloroplasts along valve inner wall (Fig. 3, arrowheads). Valves lanceolate with parallel to sub–parallel margins, tapering towards rounded poles (Figs 6–14, 17, 18); length 11.5–87.5 µm, width 5.0–7.5 µm. Cells elongated, rectangular in girdle view (Figs 15, 16), larger cells gently arcuate, possibly initial cells (Figs 6, 7). Valve face flat (Fig. 19), with transition to valve mantle gently steeped (Figs 19, 22). Transapical plane of valve rectangular to trapezoidal. Striae density at valve center 10–12 in 10 µm. Striae parallel on valve face, becoming slightly radiate at pole (Figs 7–14, 17). Each stria (width: 0.2 µm, 'a' in Fig. 33) consisting of a cribrate areola with several vimines (Figs 21, arrowheads, 22), continuing up to edge of valve (Figs 19, 22). Its outside edge bends through a right angle at junction between valve face and mantle (Figs 19, 22). Viewed internally, most of areolae sunk deeply between short ribs (virgae) (Figs 20, 21). Sternum wide lanceolate and occupying at least half of valve surface (Figs 7–14, 17). Single rimoportula at one end of sternum (Figs 17, 18, arrows), off-center and aligned with stria, opening to exterior as small rectangular slit pore (Fig. 23, arrow), internally as a shallow process (Fig. 24, arrow). Distinct ocellulimbus at both poles (0.47–0.80 µm, asterisks in Figs 23–26 and 'b' in Fig. 36), swelling at center (Fig. 25, double arrowhead). Ocellulimbus composed of 6–8 rows of 8–9 poroids, enclosed by a small rim. Rim on its advalvar side is plain, without spines or flaps. Externally, areolae do not reach poles but terminate in a single row of unoccluded small pores (Figs 23, 25, arrowheads). Mature cingulum consisting of 4–6 girdle bands (Figs 27–29), open at one pole, divided into two types: Valvocopula (VC) has a crenulated edge (pars interior) fitting on top of valve ribs (Figs 29, 30, arrowheads), without areolae (Fig. 30); copulae (3) narrower and thinner than valvocopula, with uniseriate row of areolae (Fig. 29), without fimbriae.

Type:—JAPAN. Keihin Canal (35˚ 63' N, 138˚ 75' E), the estuary of Meguro River, Konan, Minato-ku, Tokyo, collected from surface of *Caloglossa ogasawaraensis*, *K. Mitsuishi, 3 August 2008* (holotype BM! 101792, illustrated in Fig 6; isotype MTUF! AL 43062).

Etymology:—The specific epithet "kobayasii" is dedicated to the late Dr. Hiromu Kobayasi in recognition of his significant contribution to taxonomic research in diatoms.

Ecology:—With the sampling program undertaken, salinity ranges of 10.7–15.4, 8.1–25.6, 7.6–19.9 and 4.7–13.7, and temperature ranges of 8.3–27.2 ºC, 15.0–32.3 ºC, 11.5–28.0 ºC and 18.8–27.5 ºC were recorded in estuary of Naka River, Meguro River, Tsurumi River and Matsukoshi River respectively (Table 2), where *Tabularia kobayasii* was found growing abundantly (46.7–96.6% relative abundance) as an epiphyte on *Caloglossa ogasawaraensis* for a full year (predominantly summer and autumn months). *Tabularia kobayasii* can be described as a brackish-water, epiphytic diatom with high rate of productivity during summer months.

TABLE 2. Temperature and salinity in the four sampling estuaries in this study. Numbers (I, IV, V and VI) correspond to those in Table 1.

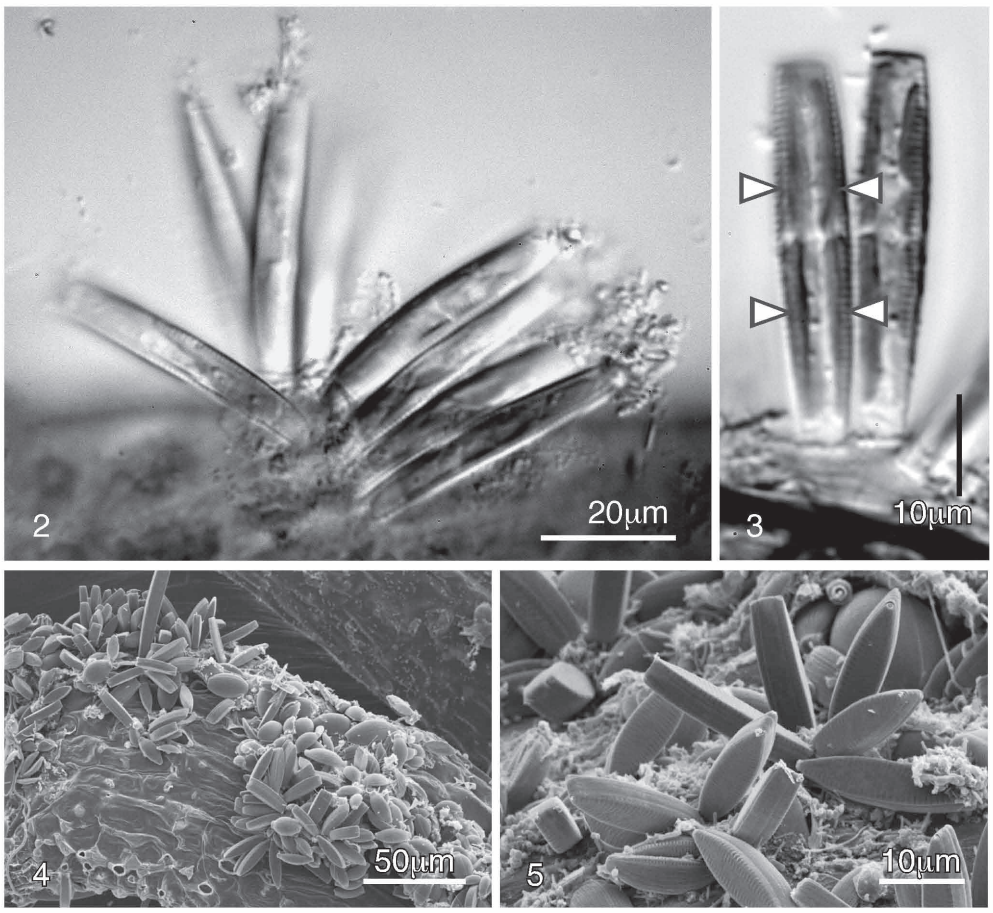
No.	Estuary		Summer	Autumn	Winter	Spring
I	Naka River	Date	31 Jul. 2008	30 Oct. 2008	11 Feb. 2009	10 May 2009
		Temperature (ºC)	27.2	15.5	8.3	18.2
		Salinity	10.7	15.4	12.8	10.7
IV	Meguro River	Date	3 Aug. 2008	13 Oct. 2008	12 Feb. 2009	24 May 2009
		Temperature (ºC)	32.3	25.0	15.0	19.5
		Salinity	8.1	15.5	25.6	15.5
V	Tsurumi River	Date	4 Aug. 2008	27 Oct. 2008	10 Feb. 2009	25 May 2009
		Temperature (ºC)	28.0	20.3	11.5	20.2
		Salinity	8.5	10.2	19.9	7.6
VI	Matsukoshi River	Date	2 Sep. 2008	28 Oct. 2008	n.d.	9 May 2009
		Temperature (ºC)	27.5	18.8	n.d.	20.5
		Salinity	9.6	13.7	n.d.	4.7

n.d.: no data.

Observations:—*Tabularia kobayasii* can be compared to: *Tabularia barbatula* (Kützing) D. M. Williams & Round (1986: 322) (basionym: *Synedra barbatula* Kützing 1844: 68), *T. fasciculata* (C. Agardh) D. M. Williams & Round (1986: 326) (basionym: *Diatoma fasciculata* C. Agardh 1812: 35), *T. investiens* (W. Smith) D. M. Williams & Round (1986: 324) (basionym: *Synedra investiens* W. Smith 1856: 98), *T. parva* (Kützing) D. M. Williams & Round (1986: 324) (basionym: *Synedra parva* Kützing 1849: 46), *T. variostriata* M. A. Harper in Harper *et al*. (2009: 293) and *T. waernii* Snoeijs in Snoeijs & Kuylenstierna (1991: 352). The fine structures of the valves of *Tabularia*, such as areolae, ocellulimbus and cingulum, have been described in detail for these species (*Tabularia barbatula* in Williams & Round 1986; *T. fasciculata* in Williams & Round 1986, Snoeijis 1992 and Kuriyama *et al*. 2008, *T. investiens* in Williams & Round 1986 and Kuriyama *et al*. 2010, *T. variostriata* in Harper *et al*. 2009 and *T. waernii* in Snoeijs & Kuylenstierna 1991). Their characteristics can be summarized as following: they have araphid valves; the valves are elongate, linear or lancolate; the striae are transverse, separated internally by distinct ribs; the areolae are occluded externally by cribra with distinct cross bars; they have an ocellulimbus, which is small, with few poroids per plate; there is one rimoportula situated close to ocellulimbus; and the cingulum consists of a few open, ligulate bands.

Our SEM observations on *Tabularia kobayasii* confirm it is a member of *Tabularia*. It is most similar to *T. investiens* and *T. variostriata* as these species have cribra with heavily silicified cross-members in structure of areolae. All three species, *Tabularia kobayasii*, *T. investiens* and *T. variostriata*, belong to "Group 2" of Williams & Round (1986). The cingulum of the three species is typical in having a non-areolate open valvocopula and several open copulae with a single row of poroids.

The following features distinguish *T. kobayasii* from *T. investiens* and *T. variostriata*, are thus diagnostic for *T. kobayasii* (listed in Table 3): a) lanceolate valves; b) narrow striae; c) small ocellulimbus; and d) denser vimines.



FIGURES 2–5. *Tabularia kobayasii*. Epiphytic on *Caloglossa ogasawaraensis* from Keihin Canal, Meguro River Estuary collected in 18 June 2008, LM (2, 3) and SEM (4, 5). 2. Living tufted and band–like colonies. 3. Living cells attached by small mucilage pads. Arrowheads indicate four plastids after cytokinesis. 4, 5. Tufted colonies.

TABLE 3. Comparison of *Tabularia kobayasii* with *T. investiens* and *T. variostriata* in morphological attributes.

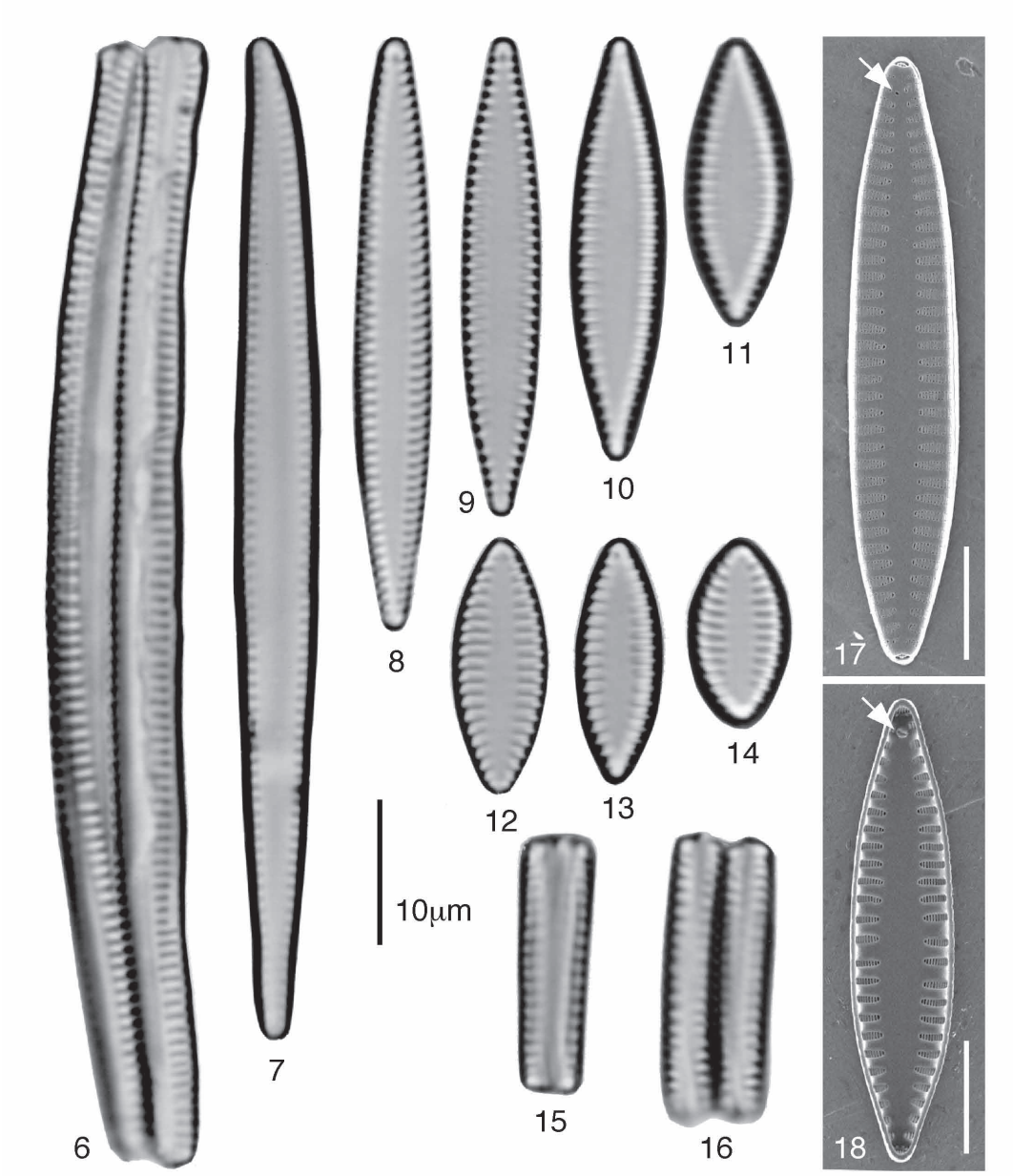
Characteristics	*T. kobayasii*[a]	*T. investiens*[a, b, c]	*T. variostriata*[d]
Structure of colony	tufted or band-like	tufted or band-like	tufted
Length of valve (μm)	11.5–87.5	[b]25.0–35.0, [c]15.0–97.0	60.0–200.0
Width of valve (μm)	5.0–7.5	[b]2.0–4.0, [c]3.0–5.0	5.0–10.0
Valve			
Valve outline	lanceolate	linear–elliptical, tapering towards rounded poles	linear to linear–lanceolate, nearly isopolar to distinctly heteropolar
Girdle view	elongate and rectangle	elongate and rectangle	elongate and rectangle
Valve face	plane	convex	plane
Mantle	present	absent	present
Shape of sternum	wide lanceolate	narrow lancolate	wide lanceolate, with undulated edge
Density of striae in 10μm	10–12	[b]n.d., [c]7–13	11–16
Structure of stria	a cribrate areola with vimines	a cribrate areola with vimines	a cribrate areola with vimines
Width of stria (a in Fig. 33) (μm)	0.2	0.6[a]	0.4
Density of vimines in 1μm	10	5	3
Number of rimopotula	1	1 or 2	2

... continued on the next page

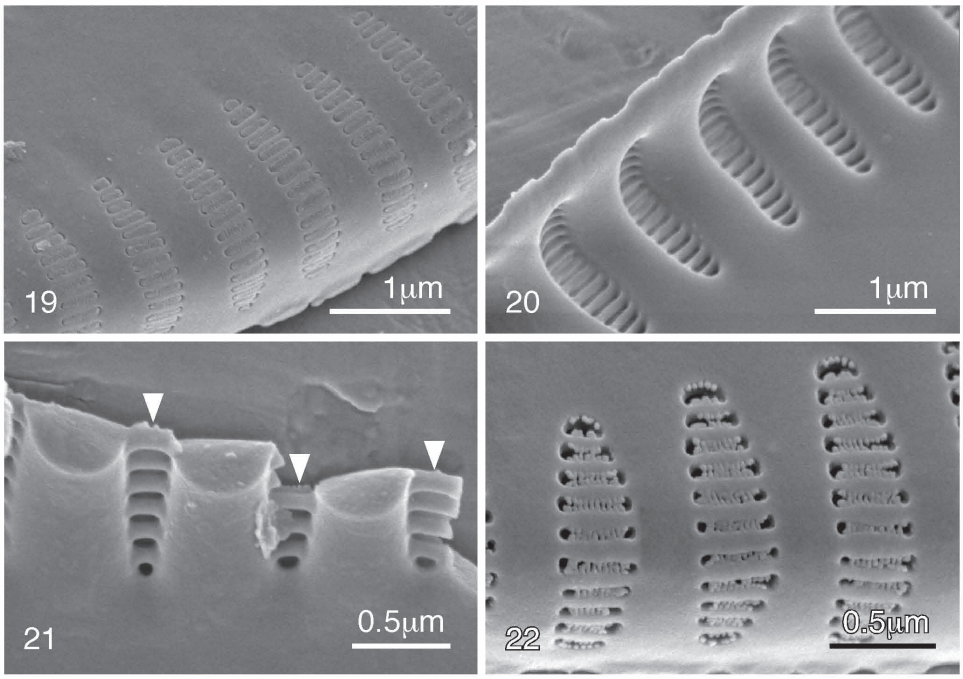
TABLE 3. (Continued)

Characteristics	*T. kobayasii*[a]	*T. investiens*[a, b, c]	*T. variostriata*[d]
Width of ocellulimbus (b in Fig. 36) (μm)	0.47–0.80	1.00–1.87[a]	n.d.
Width of ocellulimbus / width of valve	0.10–0.24	0.29–0.51[a]	n.d.
Spines overhang ocellulimbus	absent	absent	present
Girdle bands			
Number of bands	4–6	5–7	4
Valvocopula	non–areolate open band	non–areolate open band	non–areolate open band
Shape of inner edge	slightly crenulate	slightly crenulate	slightly crenulate
Copulae	open bands with a single row of poroids	open bands with a single row of poroids	open bands with a single row of poroids
Shape of inner edge	smooth	smooth	n.d.

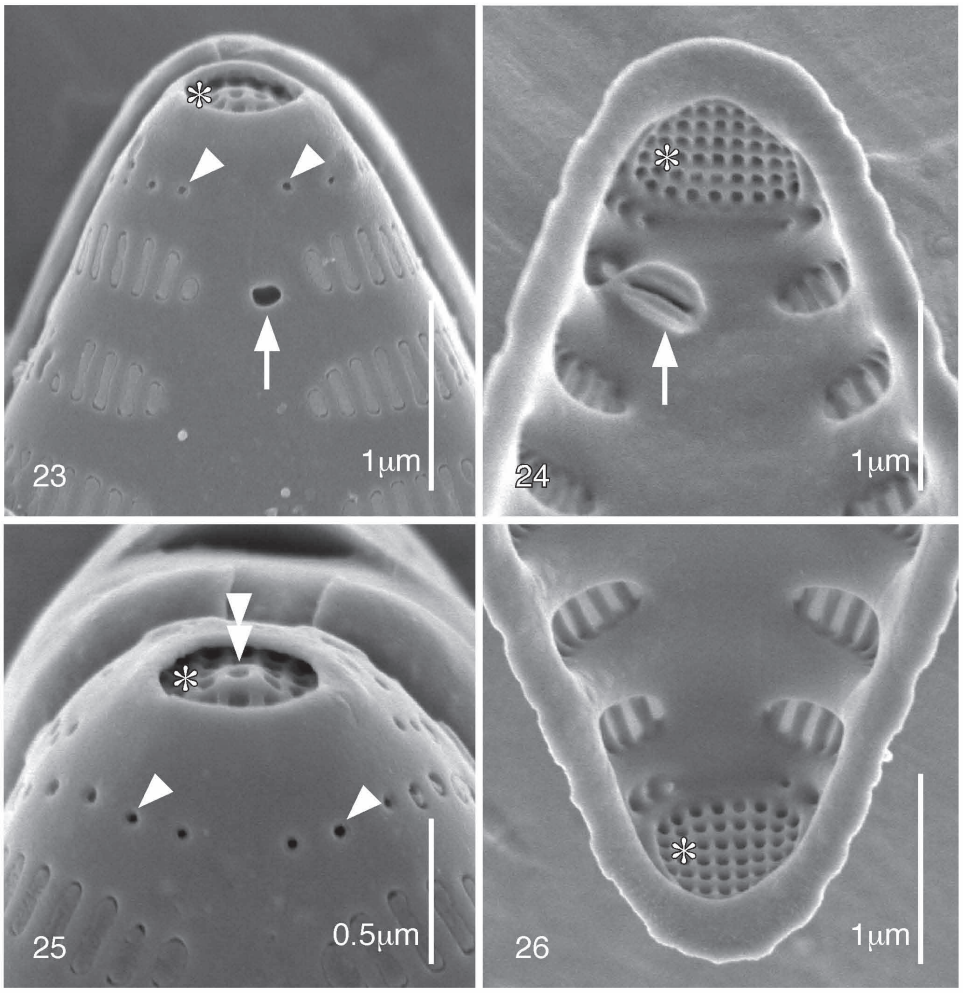
[a]This study, [b]Williams and Round (1986), [c]Kuriyama *et al.* (2010), [d]Harper *et al.* (2009), n.d.: no data.



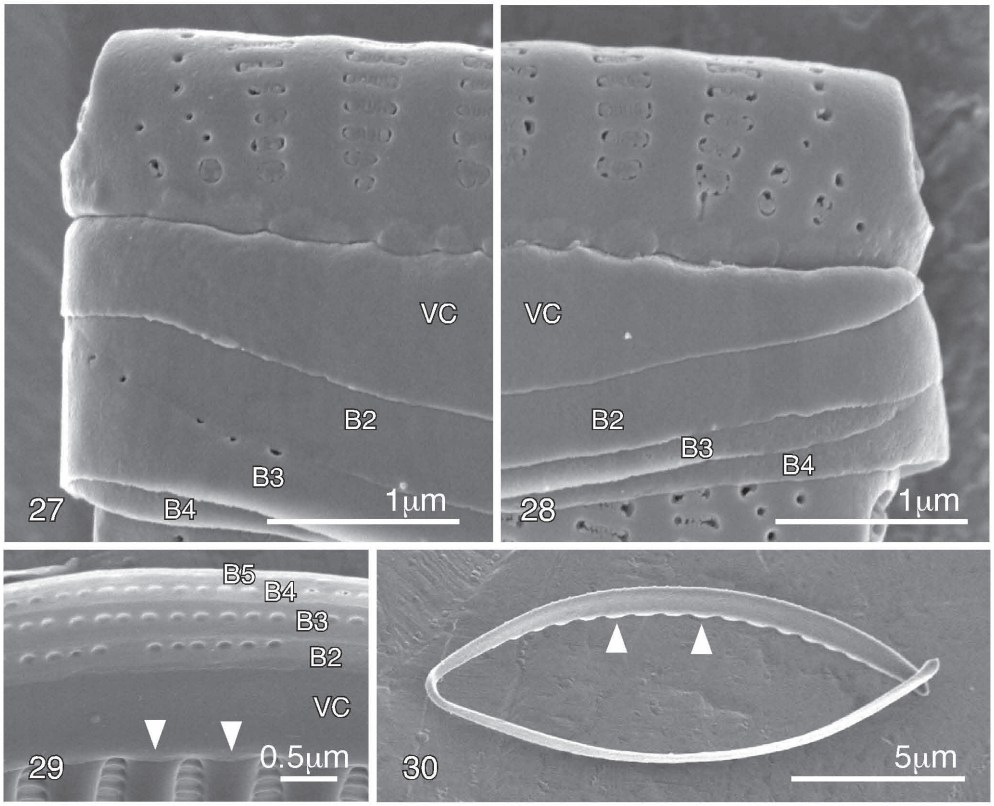
FIGURES 6–18. *Tabularia kobayasii*. LM (6–16) and SEM (17, 18), holotype and other specimens. 6, 16. Girdle views of two frustules. 7–14. Valve views. 6, 7. Initial valves. 8. Specimen from holotype slide. 15. Girdle view of a frustule. 17. External view of a whole valve. Arrow indicates the opening of rimoportula. 18. Internal view of a whole valve. Arrow indicates the rimoportula. Scale bars = 5 μm (17, 18).



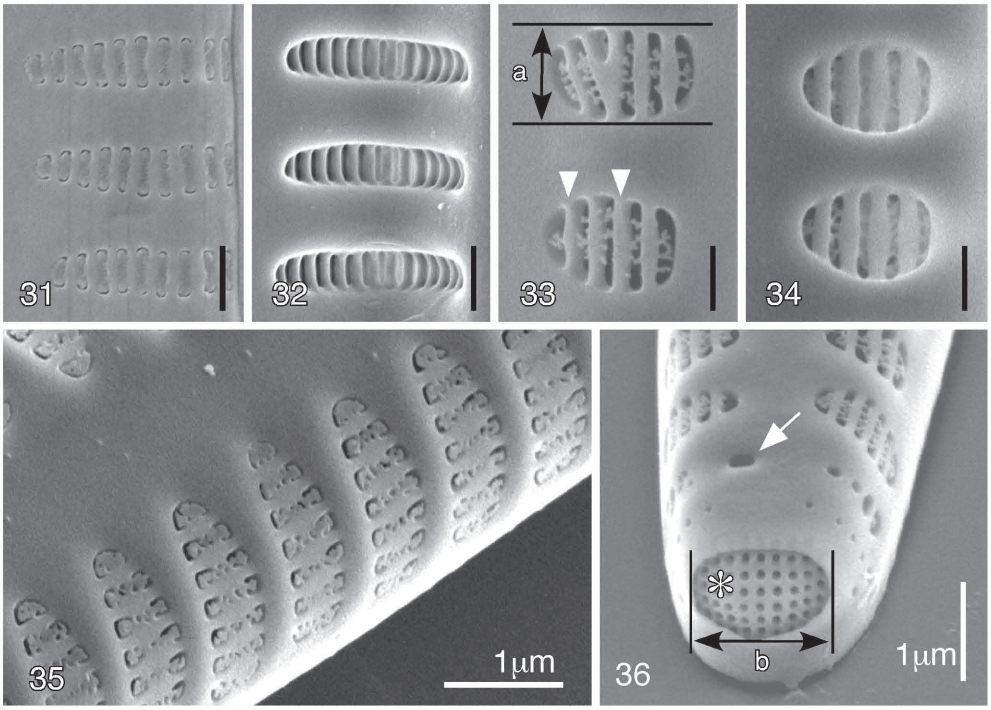
FIGURES 19–22. *Tabularia kobayasii*. SEM. 19. External view of valve mantle showing the areolae with cross-bars (= vimines). 20. Internal view of the areolae. 21. Detail of the cross section of areolae. Arrowheads indicate cross-bars (= vimines). 22. External view of immature areolae.



FIGURES 23–26. *Tabularia kobayasii*. SEM. 23, 25. External polar views showing the ocellulimbus (asterisks), the opening of rimoportula (arrow) and the tiny simple pores (arrowheads). 25. Double arrowhead indicates a small bulge of ocellulimbus. 24, 26. Internal polar views showing the ocellulimbus (asterisks) and a rimoportula (arrow).



FIGURES 27–30. *Tabularia kobayasii*. SEM. 27, 28. Terminal views of the same cingulum composed of a valvocopula (VC) and three bands (B2–B4). 29. Internal view of a valvocopula (VC) and four bands (B2–B5). Arrowheads indicate the crenulated pars interior of valvocopula. 30. Valvocopula. Arrowheads indicate the crenulated pars interior.



FIGURES 31–36. *Tabularia kobayasii* (31, 32) and *T. investiens* (33–36). SEM. 31, 33. Detail of external views of cribrate areolae. Arrowheads indicate the cross-bars (= vimines). 32, 34. Detail of internal views of areolae. 35. External view of valve face showing the areolae. 36. External polar view showing the ocellulimbus (asterisk) and the opening of rimoportula (arrow). Scale bars = 0.5 μm (31–34). 'a': length of the minor axis of areola, 'b': length of the major axis of ocellulimbus. See Material and Methods for details.

Tabularia kobayasii can be readily distinguished from *T. investiens* as the latter has a linear-elliptical valve outline, a convex valve plane (Fig. 35), a narrow lanceolate sternum, wider striae (0.6 μm, Figs 33, 34), a larger ocellulimbus (1.00–1.87 μm, Fig. 36) and less dense vimines (5 in 1 μm, Fig. 33); it can be also differentiated from *T. variostriata* by the latter having a different valve outline and shape of its sternum, and the rim structure of the ocellulimbus: *T. variostriata* has nearly isopolar to distinctly heteropolar valves, striae of various lengths forming an undulated edge to wide lanceolate sternum, and two to four advalvar spines on the rim of the ocellulimbus-type pore-fields (Harper *et al*. 2009).

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