

***Pseudachnanthidium megapteropsis* gen. nov. and sp. nov. (Bacillariophyta): a widespread Indo-Pacific elusive taxon**

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Abstract – A small marine benthic diatom pertaining to the order Achnanthes (Bacillariophyta) was observed from the Scattered Islands ("Eparses", Mozambique Channel, Indian Ocean) and from Napuka Atoll (North of the Tuamotu Archipelago, South Pacific). The latter taxon has unique characteristics (e.g., raphe valve striae composed of small areolae versus macroareolae on the sternum valve, low and plain mantle, simply hooked terminal raphe endings, high and complex cingulum composed of plain and open cingular bands, presence of a vestigial raphe) matching none of the genera split from *Achnanthes* Kützinger sensu lato (e.g., *Planolithidium* Round & Bukhtiyarova, *Karayevia* Round & Bukhtiyarova ex Round, *Psammothidium* Bukhtiyarova & Round, *Rossithidium* Round & Bukhtiyarova), neither the new genus *Madinithidium* Witkowski, Desrosiers & Riaux-Gobin from which the striae of both valves are composed of macroareolae and the terminal raphe endings are doubly hooked. *Pseudachnanthidium megapteropsis* sp. nov. and gen. nov. is proposed. Due to its small size and to the fact that its striation is not discernible using light microscopy, the new taxon probably escaped the attention of taxonomists in the past. This taxon is found along with *Madinithidium flexuistriatum* that has close but distinctive morphology, clearly marked off under scanning electron microscope (SEM). Observation with a SEM is essential to differentiate the two latter small-celled and elusive taxa that have overlapping ecological niches. It remains unknown whether *Pseudachnanthidium megapteropsis* is a cosmopolitan-tropical taxon or if its environmental tolerance is wider. Two other small taxa possibly pertain to the same new genus: one from Reunion Island (Mascarene Archipelago, Indian Ocean) and the second from the Scattered Islands (Mozambique Channel).

Achnanthes / Scattered Islands (Mozambique Channel) / Napuka atoll (South Pacific) / Bacillariophyta / Achnanthidiaceae / macroareolae / Indo-Pacific Basin

INTRODUCTION

Tropical marine benthic diatoms, e.g., from coral reef environments and particularly from the South Pacific, are relatively poorly documented (see Greville, 1865; Hagelstein, 1938; Montgomery, 1978; Foged, 1987; Coste & Ricard, 1990; Ricard, 1975; Ricard, 1977; Hein *et al.*, 2008; Navarro & Lobban, 2009; Lobban *et al.*, 2012). This is despite the fact that their diversity is high (see e.g.,

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Montgomery, 1978 and Lobban & Jordan, 2010). Plankton diatoms are quantitatively less abundant than Dinophyceae and Coccolithophoridae on atolls (Ricard *et al.*, 1979), but they seem to be highly diversified (Stanca *et al.*, 2013) and the benthic diatom assemblages are very poorly documented (Ricard, 1985).

We focused our attention on Achnanthes during a 2009 expedition (COral SAnd DIatoms off Mascarenes and Eparses, COSADIME) to the Scattered Islands (“Eparses”, ancient coral islands from the Mozambique Channel, Indian Ocean) and during a 2012 expedition (Coral Reef DIatoms, CORDIA) to Napuka Atoll (Tuamotu Archipelago, South Pacific).

Achnanthes, as monoraphid diatoms, are interesting in terms of their evolution and phylogeny. Numerous species have been included in the past in the so-called catch all genus *Achnanthes* sensu lato (e.g., Hustedt, 1937, Patrick & Reimer, 1975). The heterotypic genus *Achnanthes* sensu lato has been subject to thorough studies, and numerous new taxonomic entities have been established, with *Achnanthes* sensu stricto typified by *A. adnata* Bory de Saint-Vincent (Round *et al.*, 1990). *Achnanthidium* Kützing appeared in the beginning of the 1990’s amongst genera either revitalized or newly established. As a first attempt, Round *et al.* (1990) revitalized *Achnanthidium*, outlining the too broad generic features, so that further splits have been necessary. By now, *Achnanthidium* sensu stricto only includes taxa conforming to the generitype, e.g., *A. microcephalum* Kützing. Bukhtiyarova & Round (1996) and Round & Bukhtiyarova (1996) split a few genera from *Achnanthidium* sensu lato as previously suggested by Round *et al.* (1990). Included in this group are i.e., *Planothidium* Round & Bukhtiyarova, *Karayevia* Round & Bukhtiyarova, *Psammothidium* Bukhtiyarova & Round and *Rossithidium* Round & Bukhtiyarova. Nevertheless the concept of *Achnanthidium* sensu lato has been recently applied in the description of very small species from coral reef habitats in the Indian Ocean (Riaux-Gobin *et al.*, 2010) since they were matching none of the cited new genera (see above). Desrosiers *et al.* (2014) introduced the genus *Madinithidium* Witkowski, Desrosiers & Riaux-Gobin to accommodate their new taxon *Madinithidium undulatum* Desrosiers & Witkowski along with several taxa previously described as *Achnanthidium* sensu lato by Riaux-Gobin *et al.* (2010). Never the less the new taxon here described has unique features. In consequence we named the new taxon *Pseudachnanthidium megapteropsis* gen. and sp. nov. The new genus features are compared with those of several allied taxa (Table 1). *Pseudachnanthidium megapteropsis* is present on both poles of the Indo-Pacific Basin and may be tropical-ubiquitous. Two other rare taxa, respectively from Reunion Island (Mascarenes) and from Juan de Nova Island (Scattered Islands), probably pertain to the new genus, but need more observation before full description.

MATERIAL AND METHODS

Numerous samples from the Scattered Islands were examined, particularly GLO11 and GLO11-*Ceramium* sp. from Grandes Glorieuses Islands (11° 35.059’ S, 47° 17.316’ E) and JDN2 from Juan de Nova Island (17° 02.798’ S, 42° 43.673’ E). From Napuka Atoll we particularly examined 10NPK3-1, an intertidal turf growing on fine coral sands (14° 10.454 S; 141° 16.015 W). The samples were preserved in formaldehyde (10% final concentration). For scanning

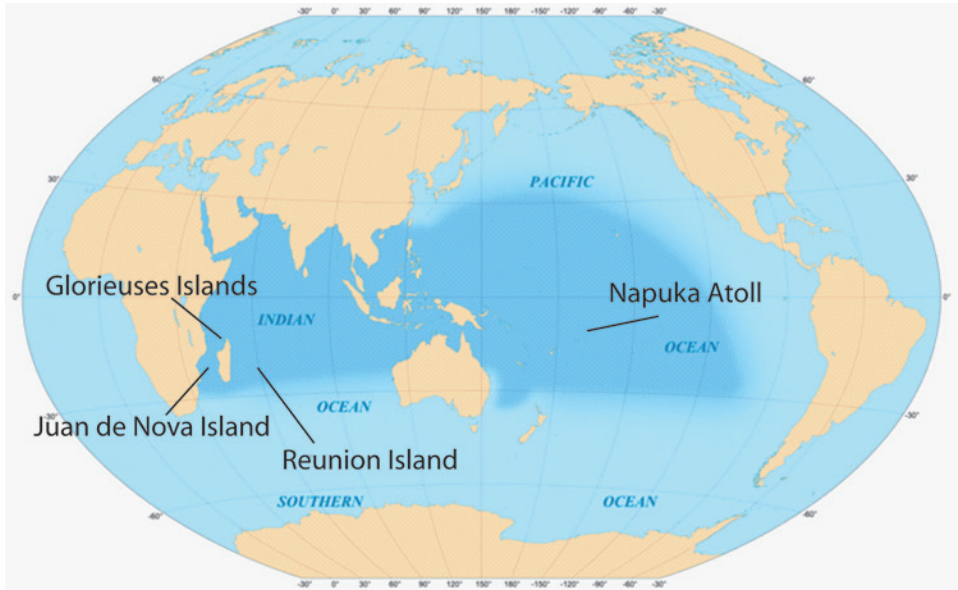


Fig. 1. Indo-Pacific Basin map, with position of Napuka Atoll (Tuamotu Archipelago, South Pacific), Reunion Island (Mascarenes, Indian Ocean) and Juan de Nova and Glorieuses Islands (Scattered Islands, Mozambique Channel).

electron microscope (SEM) examination, the samples were filtered through 1 μm Nuclepore[®] filters and rinsed twice with deionised (milliQ) water to remove salts. Filters were air-dried and mounted onto aluminum stubs before coating with gold-palladium alloy (EMSCOP SC 500 sputter coater) and examined with a Hitachi S-4500 SEM operated at 5 kV (C2M, Perpignan University, France). For light microscope (LM) examination, the samples were washed with distilled water to remove salts, treated with 30% H_2O_2 for 2 h at 70°C to remove organic matter, rinsed several times in distilled water, alcohol-desiccated and mounted on glass slides using Naphrax[®]. Diatom slides were examined with a Zeiss Axiophot 200, with differential interference contrast (DIC) optics and photographed with a Canon PowerShot G6 digital camera (CRIOBE-USR 3278 CNRS-EPHE-UPVD, Perpignan, France and Palaeoceanology Unit, University of Szczecin, Poland).

The LM illustration of the new taxon (Figs 2-6) does not give a reliable overview of its particular features (e.g., striation on both valves, exact position of the central raphe endings). Therefore, according to Article 40.2 of the International Code of Nomenclature (McNeil *et al.*, 2012) we designated SEM figure(s) as the holotype showing the best diagnostic features of the new species. Although it is a challenge to permanently preserve specimens on stubs, they are referenced and kept in an air-dried container at CRIOBE-Perpignan University, France. Isotypes are designated from slides made from the same sample in which the new taxon was observed. All morphometric data are presented in Table 2.

The general terminology used for the diatom frustules follows Anonymous (1975) and Ross *et al.* (1979).

OBSERVATIONS

The described achnantheid diatoms (see below) have in common features that match none of the five genera spilt from *Achnantheidium* sensu lato (see Round & Bukhtiyarova, 1996, Bukhtiyarova & Round, 1996 and Desrosiers *et al.*, 2014). Several features are sufficiently unique (particularly concerning the SV and RV striation, the cingulum thickness and the terminal raphe fissures) to propose the new genus *Pseudachnantheidium* (see discussion and Table 1).

Order: Achnanthes P.Silva

Family: Achnanthesiaceae D.G.Mann in Round *et al.* 1990

Genus: *Pseudachnantheidium* Riaux-Gobin gen. nov.

Pseudachnantheidium Riaux-Gobin gen. nov.

Diagnosis: Rectangular in cingular view. Dense striation on both valves. **Sternum valve (SV)** flat. Striae composed of narrow macro-areolae closed by hymenes under the valve face. Virgae strongly raised. SV Sternum with a vestigial raphe. SV valvocopula (SVVC) open and lacking fimbriae. **Raphe valve (RV)** striae uniseriate composed of minute and dense areolae. Short mantle void of areolae. Terminal raphe endings close to the margin, externally simply hooked on the same side; central raphe endings well apart, externally slightly bent on the primary side. Cingulum complex, high, composed of numerous narrow open bands without foramina.

Etymology: *Pseudachnantheidium* (prefix from the Latin “pseudo”: false) refers to characteristics close to, but different from, those in *Achnantheidium*.

Typus generis: *Pseudachnantheidium megapteropsis* Riaux-Gobin et Witkowski sp. nov.

Pseudachnantheidium megapteropsis Riaux-Gobin et Witkowski sp. nov. (Figs 2-6, LM; Figs 7-18, SEM; Figs 14-15, holotype; Table 2)

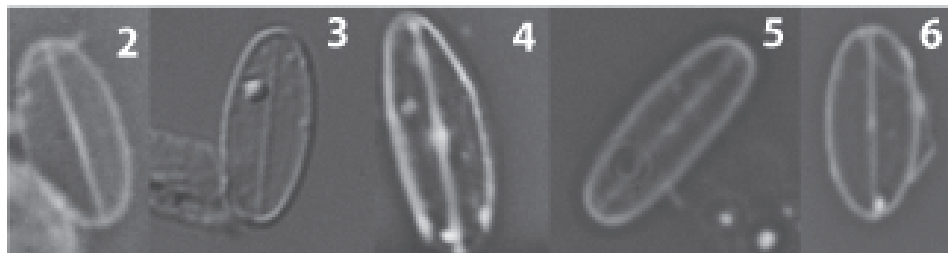
Measurements: Specimens from Napuka Island and Scattered Islands, see details in Table 2.

Diagnosis: Cells solitary, rectangular in girdle view, not V-shaped, elliptical to oblong-elliptical, length < 7.6 μm , length/width < 2.25. **SV:** strongly silicified, with a sternum straight and narrow (not enlarged in mid-valve). Striae dense and slightly undulating, parallel in mid-valve to only very slightly radiate at apices. Regular striae and interstriae. Presence of some rare short marginal striae (Figs 7-8). Each stria is composed of one macroareola (see definition by Bukhtiyarova 2006) closed by hymenes below the valve face (Figs 10-12) with no apparent slits (Fig. 12). Vestigial central raphe endings in mid-valve, also identifiable on the internal side (Fig. 13, arrows). Complex cingulum composed of up to 5 narrow bands without foramina (Figs 10-11, 15), open at apex (Fig. 10, SVVC, arrow) or laterally (Fig. 11, arrow). SVVC without fimbriae (Fig. 13, arrowhead), never observed separately (the cingulum seems well-knit). **RV:** weakly silicified, often broken due to sample treatment. Areolae round, minute and equidistant (ca 10 areolae in 1 μm). Central raphe endings simple, clearly apart and slightly bent toward the primary side (Figs 14, 17, white arrows). Terminal raphe endings simply hooked on the short mantle, both open towards the same side (secondary side, Fig. 17, framed arrows). RV internal view not observed.

Holotype: Figs 14-15, original pictures (SEM 141212-57-58) in Collection C. R.-G. (CRIOBE-USR 3278 CNRS-EPHE-UPVD, Perpignan, France), from the stub 6 (14 12 2012) from sample 10NPK 3-1.

Table 1. *Pseudachnanthidium* gen. nov. and allied genera features (see text).
nd = no data

	<i>Achnanthisidium sensu stricto</i>	<i>Psammothidium</i>	<i>Madinithidium</i>	<i>Rossithidium</i>	<i>Pseudachnanthidium</i>
Valve shape size	oblong-elliptic to linear-elliptic variable, generally small	lanceolate-elliptic to linear-elliptic (SV concave, RV convex) small	variable small	oblong-elliptic to linear-elliptic RV concave, SV convex variable	elliptic to oblong-elliptic, small to minute
Cell in girdle view	V shaped (arched)	rectangular	rectangular	rectangular	rectangular
RV striation repartition	areolae usually uniseriate striae denser on apices	areolae usually uniseriate regularly spaced	macroareolae regularly spaced	areolae uni- or biseriate regularly spaced	areolae uniseriate regularly spaced
SV striation repartition	areolae usually uniseriate usually denser on apices	areolae (uni- to multiseriate) regularly spaced	macroareolae regularly spaced (often similar on both valves)	areolae uni- or biseriate regularly spaced	macroareolae regularly spaced
Terminal raphe fissures	simple to curved usually on same side	curved to opposite side or absent	doubly hooked, in same direction	absent	simply hooked in same direction (secondary side)
Central raphe endings	simple, coaxial internally turned in opposite directions	simple, coaxial internally not coaxial often a stauros or a rectangular area	simple to slightly expanded, slightly bent on primary side Internally coaxial reduced, delineated by striae of different size	simple, coaxial slightly bent in opposite sides (see Potapova, 2012) variable	slightly curved on primary side probably coaxial reduced
RV central area	opposite directions often a stauros	rectangular area	Internally coaxial reduced, delineated by striae of different size	variable	reduced
SV central area	variable	sometimes asymmetric	reduced	variable	reduced
Vestigial raphe	no	no	no	sometimes present	present
Cingulum ornamentation	plain open bands	plain bands	plain bands	no data	numerous narrow and plain open bands
Mantle ornamentation	large one row of elongate areolae	short row(s) of pores	short to quasi-absent no ornamentation	hort areolae present	short plain



Figs 2-6. LM illustration of *Pseudachnanthidium megapteropsis* sp. nov. Specimens from Juan de Nova. Entire frustules. Scale bar = 10 μ m.

Isotypes: From sample 10NPK3-1, 24 Sept. 2012, Slide BM 101 782 deposited in the National History Museum (London, U.K.) and slide NPK2 in collection C. R.-G.

Etymology: Named in reference to the SV stria pattern resembling the ventral grooves (pleated throat grooves) observed in *Megaptera* (Humpback whale) species.

Type locality: Napuka marine coastal environment, Tuamotu (14° 10.454 S; 141° 16.315 W). Collected by C. R.-G., 24 Sept. 2012.

Substratum: Open sea area, flat reef, on a short turf composed of green and brown filamentous algae, 5 cm water deep. Sea water temperature 28°C.

Undefined allied taxa (SEM, Figs 19-22, Table 2)

Measurements: Specimens from Reunion and Juan de Nova Islands, see Table 2.

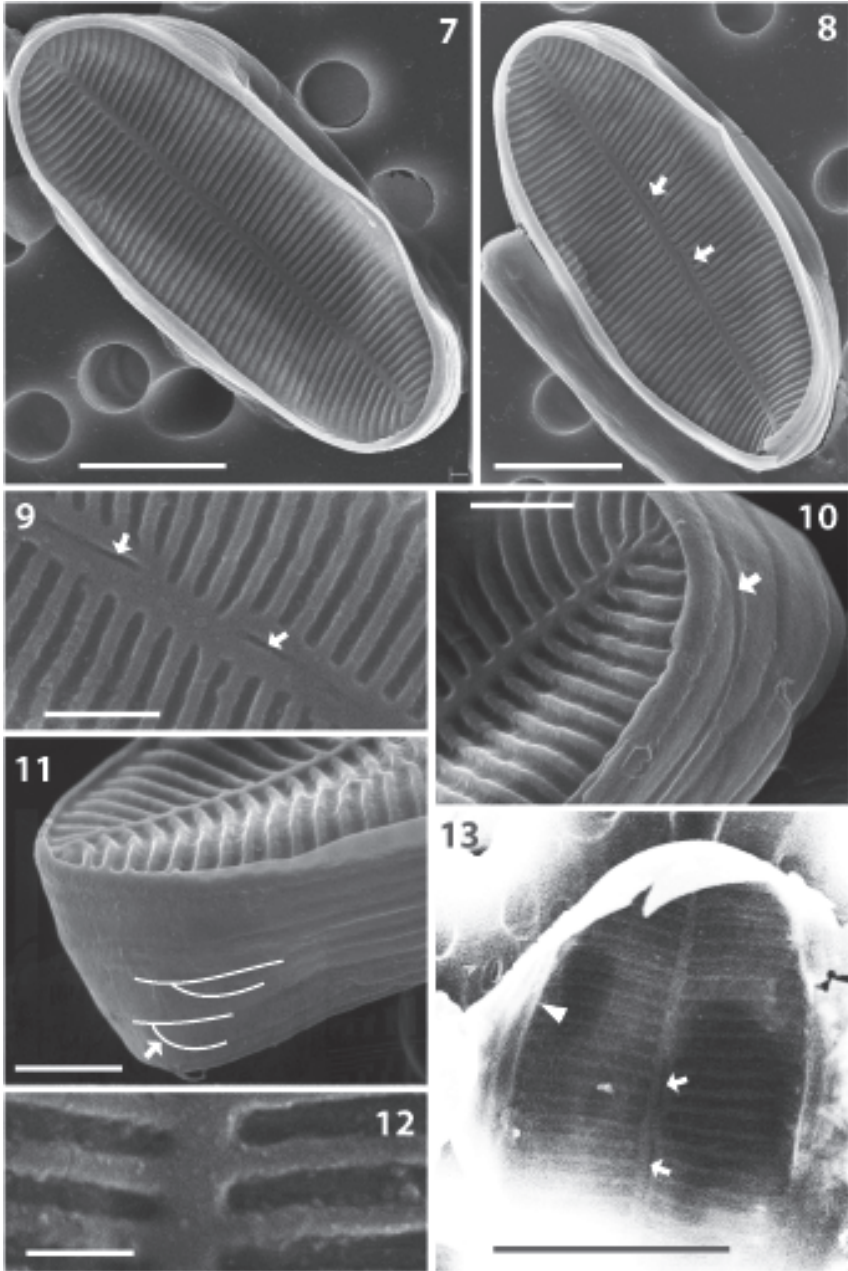
Description: Two taxa, one from Reunion Island (Figs 19, 20) and the second from Juan de Nova Island (Figs 21-22), have features close to those of *Pseudachnanthidium megapteropsis* and are assumed to pertain to the same genus. The taxon from Reunion only differs by its metrics (larger length and less dense striation on both valves, see Table 2), all other features are similar to the generitype, so that these specimens may pertain to a separate forma of the same species.

The taxon from Juan de Nova has characteristics more different than the generitype (Figs 21-22), with larger dimensions, a more linear shape (length/width > 2.75), a wider SV sternum (enlarged in mid-valve) with a vestigial raphe well identifiable not only in mid-valve but also on apices (Fig. 22, arrows).

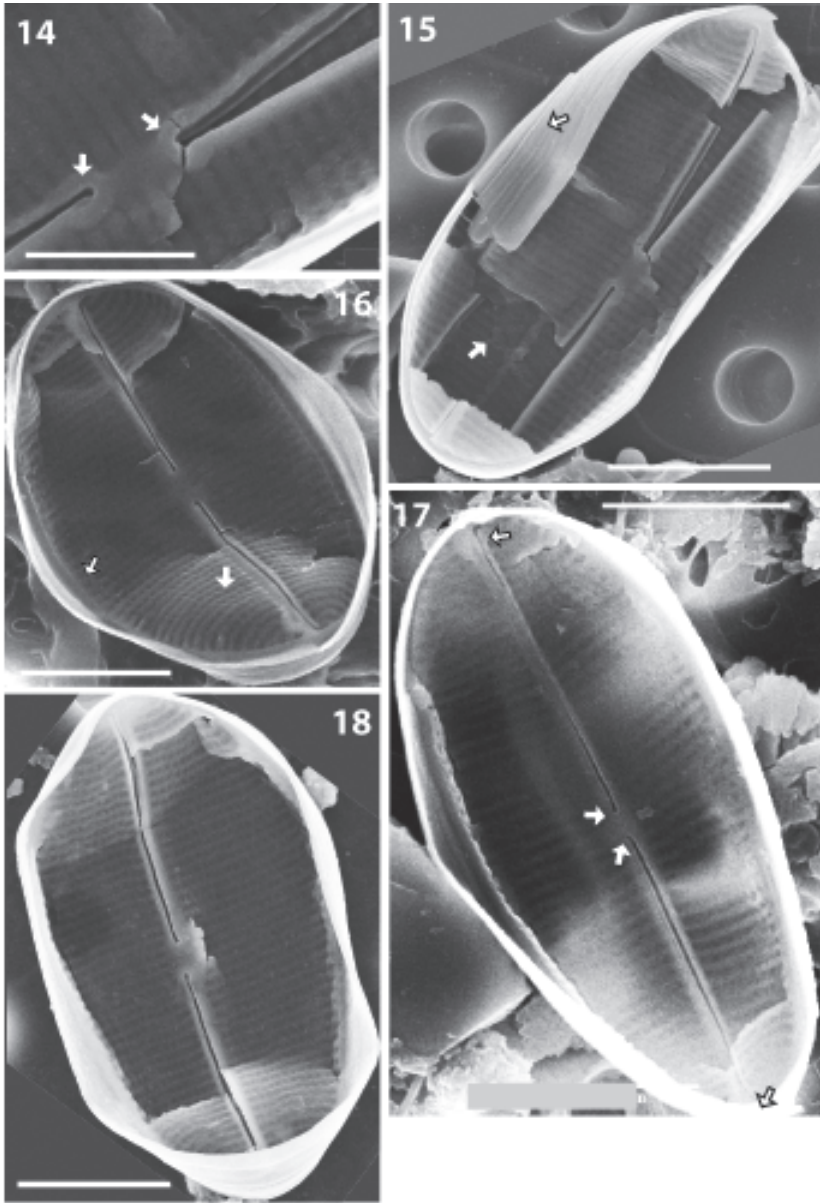
More observation is needed for the two latter taxa before full description.

DISCUSSION

Pseudachnanthidium megapteropsis sp. nov. and the two rare and undefined taxa (see above) are rectangular in cingular view and have RV striae composed of small areolae, while their SV striae are composed of macroareolae (Table 1). On both valves, the striae are equidistant and only radiate on top apices. The terminal raphe endings are simply hooked and the cingulum is high and composed of several narrow open bands without foramina. For these reasons



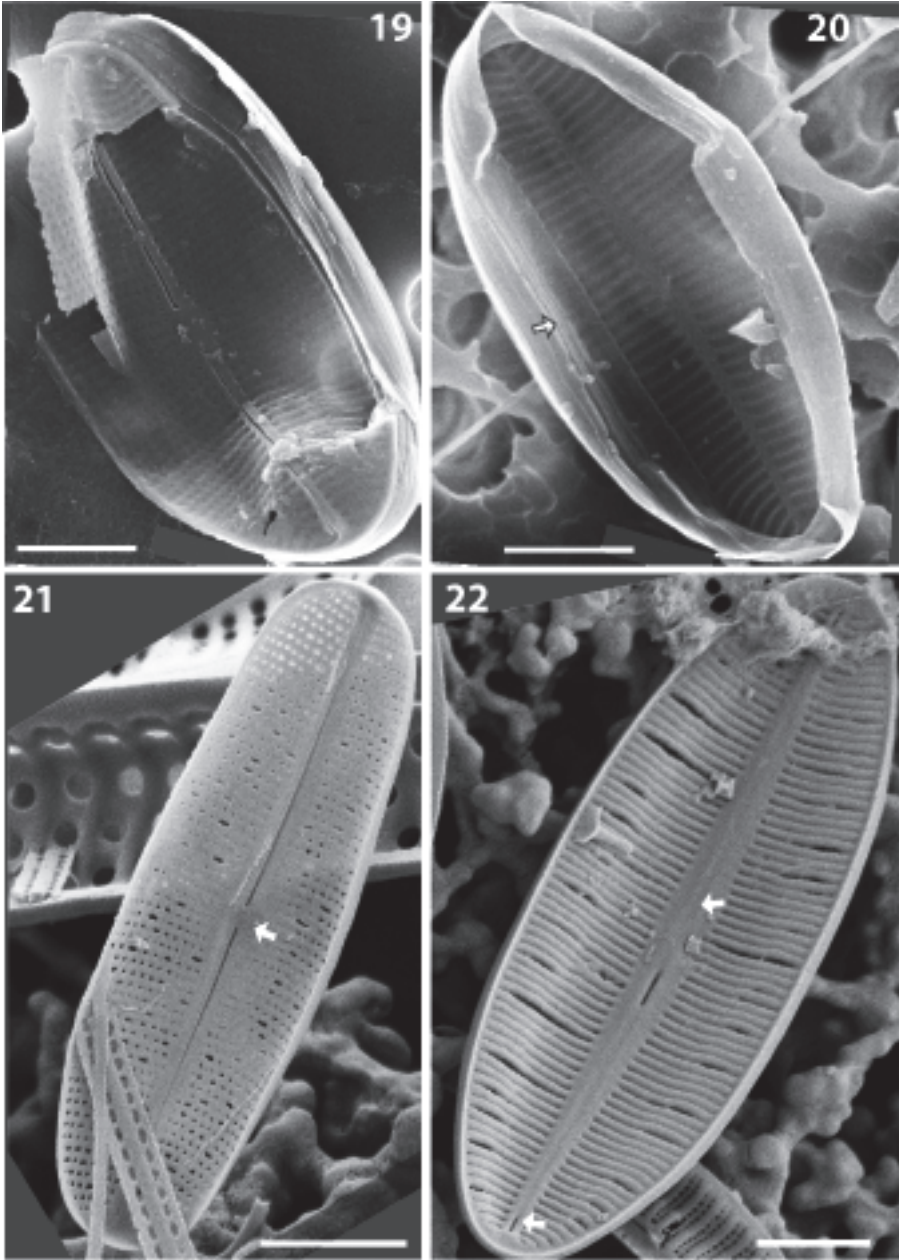
Figs 7-13. *Pseudachnanthidium megapteropsis* sp. nov. Sternum valves (SV), SEM. Specimens from Napuka. SV in external view showing the dense striation composed of macroareolae (7-8), the vestigial raphe (8-9, arrows), the high cingulum with the SV valvocopula open (10, arrow) and supplementary open bands (11, arrow), and the hymenes positioned under the valve face (12). SV internal view with stria parallel and regular, a narrow sternum and the vestigial raphe endings (arrows) (13). Scale bars = 2 μ m (Figs 7-8, 13); 600 nm (Fig. 11); 500 nm (Figs 9-10); 200 nm (Fig. 12).



Figs 14-18. *Pseudachnanthidium megapteropsis* sp. nov. Raphe valve (RV), SEM. Specimens from Napuka (14-15, holotype) and from Juan de Nova (16-18). RV in external views showing: the dense striation composed of small-sized and round areolae (Fig. 16, white arrow), striae regularly spaced, almost parallel and only radiate on apices (Figs 17-18), a marginal edge devoid of areolae (Fig. 16, framed arrow), a raphe straight with central endings bent on the same direction (Figs 14, 17, white arrows) and terminal fissures bent on the same direction opposite to that of the central raphe endings (Fig. 17, framed arrows), numerous and narrow cingular bands (Fig. 15, framed arrow). The broken RV in Fig. 15 shows the internal side of the SV with the macroareolae hymenes (white arrow) and sternum. Scale bars = 2 μm (Figs 14-17); 1 μm (Fig. 13).

Table 2. Features of *Pseudachnanthidium megapteropsis* sp. nov. and allied taxa. Length, width, stria densities = min-max (mean \pm standard deviation σ), 1 decimal. Length/width = mean \pm standard deviation σ , 2 decimals. N = specimens observed. nd = no data.

	N	Valve shape	Length (μm) Width (μm)	Length/ width	SV sternum shape and width vestigial raphe	Striation	SV striae in 10 μm	RV striae in 10 μm	Raphe shape Central raphe endings Terminal raphe endings
<i>Pseudachnanthidium megapteropsis</i> sp. nov. (Juan de Nova and Glorieuses Islands)	15	elliptic to linear-elliptic	5.7-10 (7 \pm 1.2) 2.6-4.3 (3.3 \pm 0.5)	2.10 \pm 0.23	straight, narrow vestigial raphe in the centre	striae equidistant on both valves, only radiate on apices SV macroareolae RV poroid uniseriate	65-80 (72.4 \pm 7.1)	65.1-82 (72.9 \pm 6.6)	straight well apart, bent on opposite sides simply curved on same direction
<i>Pseudachnanthidium megapteropsis</i> sp. nov. (Napuka Atoll)	10	elliptic to linear-elliptic	7.2-8.3 (7.6 \pm 0.5) 2.2-3.8 (3.2 \pm 0.6)	2.48 \pm 0.50	straight, narrow vestigial raphe in the centre	striae equidistant on both valves, only radiate on apices SV macroareolae RV poroid uniseriate	60.5-67.4 (64.5 \pm 2.2)	67.4-79.1 (70.3 \pm 5.8)	straight well apart, bent on opposite sides simply curved on same direction
<i>Pseudachnanthidium</i> spp. (Reunion Island, Figs 19-20)	3	elliptic to linear-elliptic	7.7-9.7 (8.8 \pm 1) 3-4.6 (3.6 \pm 0.9)	2.47 \pm 0.40	straight, narrow nd	striae equidistant on both valves, only radiate on apices SV macroareolae RV poroid uniseriate	60	47.5-55 (51.3 \pm 5.3)	straight well apart, bent on opposite sides simply curved on same direction
<i>Pseudachnanthidium</i> spp. (Juan de Nova Island, Figs 21-22)	4	oblong-elliptic to linear	8.8-14.1 (11.3 \pm 2.5) 3-5.2 (4.2 \pm 0.9)	2.75 \pm 0.46	slightly enlarged in mid-valve vestigial raphe in the centre and apices	striae equidistant on both valves, only radiate on apices SV macroareolae RV poroid uniseriate	52.8-60 (55.4 \pm 4)	64	straight well apart, internally coaxial low helictoglossa
<i>Madmitidium flexistriatum</i> (Juan de Nova Island, Figs 23-24)	8	elliptic	5.7-8.1 (8.1 \pm 0.1) 2.7-3.9 (3.7 \pm 0.2)	2.16 \pm 0.15	slightly enlarged in mid-valve no vestigial raphe	striae equidistant on both valves, slightly radiate SV macroareolae RV macroareolae	42-65 (54.6 \pm 7.4)	47.4-59 (53.8 \pm 5.4)	straight, filiform well apart, bent on opposite sides doubly hooked on same direction



Figs 19-22. *Pseudachnanthidium* spp. from Reunion Island (Figs 19-20), and *Pseudachnanthidium* spp. from Juan de Nova Island (Figs 21-22), SEM. RV in external view with poroid striae (Fig. 19). SV in internal view, with numerous cingular bands (Fig. 20, framed arrow). RV in internal view, with an oblong linear shape, and coaxial central raphe endings (Fig. 21, arrow). SV in external view, with strong virgae and narrow macroareolae, and vestigial raphe signature in mid-valve and apices (Fig. 22, arrows). Scale bars = 2 μ m.

the latter taxa do not pertain to the genus *Achnantheidium* Kützing *sensu stricto* (Round & Bukhtiyarova, 1996; Potapova & Ponader, 2004) as typified by *A. macrocephalum* from which the species are dorsi-ventrally bent (V-shaped), have a narrow shape, striae denser on apices, only a few cingular bands and a distinct mantle with foramina (see ref. cit., Table 1). Furthermore, *Achnantheidium sensu stricto* includes only freshwater species [even if some taxa such as *Achnantheidium sieminskae* Witkowski *et al.* (2012) are described from a marine environment but with probable freshwater inputs].

Pseudachnantheidium megapteropsis also differs from *Rossithidium pusillum* (Grunow) Round & Bukhtiyarova 1996, that has mid-valve striae less dense than on apices (Lange-Bertalot & Krammer, 1989, pl. 64, p 294, Figs 31-43) and SV striae composed of a row of uniseriate areolae (Table 1).

The new taxon has some similarities with the genus *Psammothidium* (Bukhtiyarova & Round, 1996; Wojtal, 2004; see the contradictory paper by Monnier *et al.*, 2007 concerning the difficulties to accurately separate *Psammothidium* species from *Achnantheidium* ones), but here again, *Psammothidium* species have SV striae composed of uniseriate areolae and have a row of areolae on the mantle (Table 1).

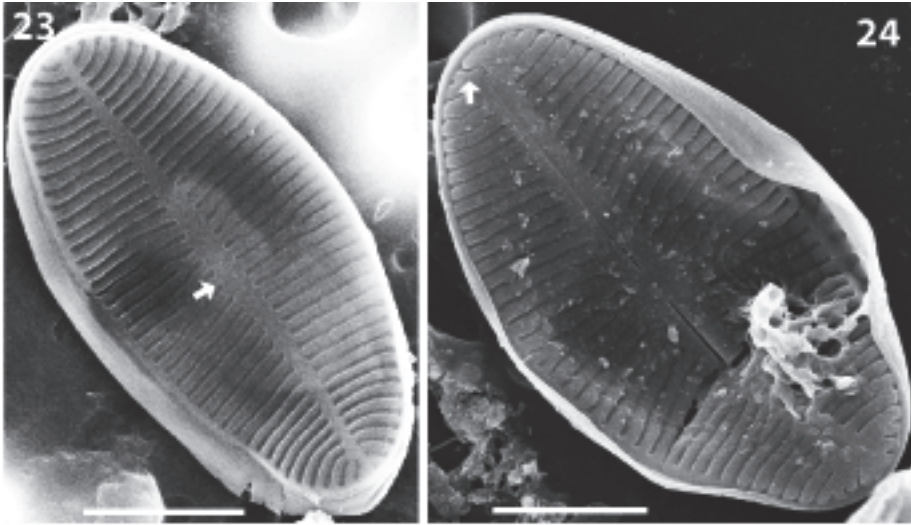
The new species also differs from *Madinithidium flexuistriatum* (Riaux-Gobin *et al.*) Witkowski, Riaux-Gobin & Desrosiers comb. nov. in Desrosiers *et al.* (2014) that has a more elliptic valve shape, striae composed of slightly radiate narrow macroareolae on both valves, SV sternum enlarged in mid-valve and doubly hooked terminal raphe endings (see Figs 23-24; Riaux-Gobin *et al.*, 2011; Table 1).

On the other hand, the vestigial raphe always present in *Pseudachnantheidium megapteropsis* is reminiscent of *Astartiella* Witkowski, Lange-Bertalot & Metzeltin in Moser *et al.*, 1998 (see also Riaux-Gobin *et al.*, 2013), a group of diatoms split from *Achnanthes sensu lato*. Note that *Rossithidium anastasiae* (Kaczmarska) Potapova also shows such a vestigial raphe (Potapova, 2012; Table 1).

Ecology-biogeography

Pseudachnantheidium megapteropsis specimens from the Scattered Islands and from Napuka Atoll have very similar features, with only stria densities slightly lower at Napuka (Table 2). On the other hand the scarce specimens from Reunion Island are bigger and show lower stria density on both valves, and thus may pertain to a different forma (see above). Some other species pertaining to the new genus (such as *Pseudachnantheidium* spp. from Juan de Nova Island, see above) will probably be discovered in the future. The small size and scarcity of *Pseudachnantheidium megapteropsis* sp. nov. are possibly the reason why it was overlooked in the past. This species, present on both poles of the Indo-Pacific Basin, is probably a cosmopolitan-tropical taxon, but its tolerance may also be wider.

At the Scattered Islands, the new taxon was found along with *Madinithidium flexuistriatum* (Desrosiers *et al.*, 2014), close by but with features clearly different (Table 2). It is only under SEM that it is possible to distinguish between *Pseudachnantheidium megapteropsis* (Figs 7-17) and *Madinithidium flexuistriatum* (Figs 23-24). The two latter taxa may be qualified as “elusive taxa”, since it is very difficult to discriminate them in LM, while relatively easy with SEM.



Figs 23-24. *Madinithidium flexuistratum* from Juan de Nova Island (Figs 23-24), SEM. SV in external view with slightly radiate macroareolae and a SV sternum enlarged in mid-valve (Fig. 23, arrow), without vestigial raphe. RV in external view, with irregular narrow macroareolae, short intercalary striae and terminal raphe endings doubly hooked (Fig. 24, arrow). Scale bars = 2 μ m.

In Reunion Island, the presence of scarce specimens very similar to our new taxon, but with a less dense striation (Table 2, *Pseudachnanthidium* spp., Figs 19-20) may imply a morphological plasticity of *Pseudachnanthidium megapteropsis* or the existence of different formae. Molecular markers would help to differentiate these morphs or nearby species, but, due to their small size, these taxa will probably be difficult to cultivate for their genetic study.

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