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Pinnularia schoelynckiana, a new limnoterrestrial diatom species (Bacillariophyta) from the sub-Antarctic Iles Kerguelen (southern Indian Ocean)

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Abstract

An unknown *Pinnularia* taxon was recorded during a survey of the limno-terrestrial diatom flora of some hot springs in the Val Travers area (Grand Terre, Iles Kerguelen, sub-Antarctic region). The morphology of the species was investigated using both light and scanning electron microscopy. Based on these results, the species could not be identified using the currently available literature and is therefore described as a new species: *Pinnularia schoelynckiana* sp. nov. The new species is characterized by rhombic-lanceolate valves, radiate, geniculate striae changing into strongly convergent near the apices and an undulating, lateral raphe. A detailed morphological comparison is made with similar *Pinnularia* species, described from the Antarctic Region and worldwide. Brief notes on the associated diatom flora and its ecology are added.

Key-words: *Pinnularia*, sub-Antarctica, morphology, new species, hot springs.

Introduction

For more than 100 years, the non-marine diatom flora of the sub-Antarctic Iles Kerguelen, a large archipelago in the southern Indian Ocean, has been the subject of several taxonomic studies. Although the first data were already published by Reinsch (1876, 1879) and Hemsley (1885), it was not until the contributions by Germain (1937) and Bourrelly and Manguin (1954) that the sub-Antarctic diatom flora of the archipelago became better known. Both papers described a large number of new taxa, despite being based on only a handful of samples. The first large overview of the Kerguelen diatom flora was later made by Le Cohu and Maillard (1983, 1986) who analyzed more than 75 samples from different parts of Iles Kerguelen, describing several of the observed species as new. Despite these publications, the non-marine diatom flora of the sub-Antarctic Region was still considered as being largely composed of cosmopolitan species (Jones 1996; Van de Vijver and Beyens 1999). Kellogg and Kellogg (2002) listed all reported taxa from Antarctica showing that most had a rather broad geographic distribution. A large taxonomic effort, revising the entire Antarctic non-marine diatom flora started almost 20 years ago, contradicting the general idea of a cosmopolitan flora in the sub-Antarctic region. Van de Vijver, Frenot, and Beyens (2002) revised the diatom flora of the nearby Iles Crozet and together with the transfer of twenty taxa (mainly described by Germain (1937) and Manguin in Bourrelly and Manguin (1954)), described another 37 new taxa, a lot of which are still recognized as being typical sub-Antarctic endemics, never found outside the sub-Antarctic Region (Van de Vijver, Frenot and Beyens, 2002; Van de Vijver, Gremmen and Beyens 2005; Zidarova, Kopalová and Van de Vijver 2016). Later studies on the sub-Antarctic Heard Island (Van de Vijver et al. 2004a) and the Prince Edward Islands (Van de Vijver, Gremmen, and Smith 2008) confirmed the presence of a typical sub-Antarctic diatom flora. Since 2010, almost every year, new taxa are added to the sub-Antarctic flora (e.g. Romero and Van de Vijver 2011; Van de Vijver 2012,

2014, 2019; Van de Vijver and Dessen 2018; Van de Vijver, de Haan, and Lange-Bertalot 2014; Van de Vijver et al. 2017, Van de Vijver, Wetzel, and Ector 2018).

During a survey of the diatom communities of the hot spring area of Val Travers in the central part of the Iles Kerguelen's main island, an unknown *Pinnularia* species was found that could not be identified using the currently available literature. In the past, this genus proved to be very species-rich in the entire Antarctic area with more than 50 new taxa (including species and varieties) described the past 65 years (Bourrelly and Manguin 1954, Van de Vijver, Frenot and Beyens 2002; Van de Vijver et al. 2012; Van de Vijver and Zidarova 2011; Zidarova, Kopalová and Van de Vijver 2012). Based on detailed light and scanning electron microscopy observations, the new species is described as *Pinnularia schoelynickiana* sp. nov. The new species is compared with similar *Pinnularia* species worldwide, mainly with species found in the southern hemisphere. Notes on its ecology and its biogeographical distribution in the sub-Antarctic region are added.

Material and methods

The French Iles Kerguelen (49°S, 69°E) is a large archipelago located in the southern Indian Ocean, ca. 4000 km from the coasts of South Africa and Australia. The archipelago, covering a total land area of 7215 km², is composed of more than 300 smaller and larger islands of which the main island, Grande Terre, is the largest of all (6500 km²). The island is mountainous, with the highest peak culminating at 1850 m a.s.l. It has an oceanic cold climate with a mean annual temperature at the Port-aux-Français weather station of 4.9 °C, with 8.2 °C (February) and 2.1 °C (July) for the warmest and coldest month respectively (Météo France Data, 1951–2017). Wind speed is generally high. Annual rainfall varies from less than 800 mm in the eastern part to more than 3200 mm on the western coast (Frenot et al., 1997), mainly in the form of rain.

The study area, Val Travers, is situated in the center of the main island Grand Terre (69°25' S, 49°19' E, 40 m a.s.l.) and contains one of the last remaining expressions of the ancient volcanic history of the archipelago. During a short stay in the austral summer of 2004–2005, a total of 24 moss samples has been collected on a transect starting close to a hot spring along the river that runs through Val Travers. At this place, the water temperature of the hot spring was 62 °C whereas the temperature in the mosses varied between 18 and 20 °C (measurements done on 31/01/2005). The new *Pinnularia* species was observed in several of the samples with the largest population being present in the immediate vicinity of the hot spring in sample B-3, the latter thus selected for further light and scanning electron microscopy observations.

The samples were prepared for LM observation following the method described in van der Werff (1955). Small parts of the samples were cleaned by adding 37% H₂O₂ and heating to 80°C for about 1h. The reaction was completed by addition of KMnO₄. Following digestion and centrifugation (three times 10 minutes at 3700 x g), cleaned material was diluted with distilled water to avoid excessive concentrations of diatom valves on the slides. Cleaned diatom material was mounted in Naphrax. Slides were analyzed using an Olympus BX53 microscope, equipped with Differential Interference Contrast (Nomarski) and the Olympus UC30 Imaging System. Samples and slides are stored at the BR-collection (Meise Botanic Garden, Belgium). For scanning electron microscopy (SEM), parts of the oxidized suspensions were filtered through a 1-µm Isopore™ polycarbonate membrane filter (Merck Millipore). The stubs were sputter-coated with a Gold-Palladium layer of 20 nm and studied in a JEOL-JSM-7100F scanning electron microscope at 1 kV at the Meise Botanic Garden, Belgium. Diatom terminology follows Ross et al. (1979) (stria and areola morphology), Krammer (2000) (overall genus morphology) and Round, Crawford, and Mann (1990) (raphe structure). The morphology of the new taxon has been compared with all known *Pinnularia*

species described worldwide (i.a. Bourrelly and Manguin 1954; Le Cohu and Maillard 1986; Krammer 2000; Rumrich, Lange-Bertalot and Rumrich 2000; Van de Vijver, Frenot and Beyens 2002; Van de Vijver et al. 2012; Zidarova, Kopalová and Van de Vijver 2012).

Results

***Pinnularia schoelynickiana* Van de Vijver, Scholberg & Lebouvier, sp. nov.** (Figs 1–26)

Description. LM(Figs 1–19): Frustules in girdle view rectangular (Fig. 1). Valves rhombic-lanceolate with weakly convex, never parallel margins and protracted, weakly capitate apices. Valve dimensions (n=25): length 53–60 μm , width 7.5–8.5 μm . Axial area very narrow near the apices, gradually but distinctly widening towards the central area. Central area relatively large, forming a wedge-shaped fascia. Shortened striae never observed in the central area. Raphe lateral, with clearly undulating raphe branches. Central raphe endings expanded, drop-like, weakly unilaterally deflected, rather distant from each other. Terminal raphe fissures elongated, hooked. Striae distinctly radiate and geniculate near the central area, becoming strongly convergent near the apices, 10–11 in 10 μm . Striae bordering the central area abruptly shortening. Longitudinal lines absent.

SEM (Figs 20–26): Mantle striae continuing till halfway the mantle leaving the mantle edge hyaline (Fig. 21). Alveoli composed of 5–6 rows of small areolae (Figs 20, 22 and 23). External raphe branches clearly undulating (Fig. 20). Central raphe endings asymmetrically expanded, almost spatulate. Raphe itself strange but spatulate expansion laterally deflected (Fig. 22). Terminal raphe fissures elongated, hooked, continuing onto the mantle (Fig. 23). Internally, raphe interrupted at the central nodule with inconspicuous, straight to weakly deflected central endings (Figs 24 and 25). Terminal endings terminating on distinct helictoglossae (Fig. 26). Alveoli opening via narrow fenestra to the valve interior (Figs 24–26). Virgae between the alveoli rather narrow, clearly raised. (Fig. 26).

Holotype. BR-4569 (Meise Botanic Garden, Belgium)

Isotype. PLP-363 (University of Antwerp, Belgium)

Type locality. Val Travers, Grande Terre, Iles Kerguelen, sub-Antarctic region, sample B-3, (leg. M. Lebouvier, coll. date 31/01/2005)

Etymology. The species is named in honour of our colleague, Dr. Jonas Schoelynck (Ecosystem Management Research Group (ECOBE), University of Antwerp, Belgium) in recognition of his work on the silicium cycle in aquatic environments.

Associated diatom species. The samples in which *P. schoelynckiana* were found, proved to be quite species rich. The holotype slide was dominated by *Fragilaria* cf. *capucina* Desmazières (21%), *Psammothidium abundans* (Manguin) Bukhtiyarova & Round (16%) and *Gomphonema* cf. *montanum* Schumann (16%). Other associated taxa include *Achnantheidium sieminskae* Witkowski et al., *A. modestiforme* (Lange-Bertalot) Van de Vijver, *Brachysira sandrae* Van de Vijver, *Chamaepinnularia muscicola* (J.B.Petersen) Kulikovskiy, Lange-Bertalot & Witkowski, *Eunotia mouroitii* Van de Vijver et al., *Kobayasiella subantarctica* Van de Vijver & Vanhoutte, and several *Psammothidium* taxa.

Ecology and distribution. *Pinnularia schoelynckiana* was found in several moss samples collected in some brooks and rivers in the Val Travers area (Kerguelen). The largest population was observed in sample B-3, a liverwort sample collected from the main hot spring at 70 m altitude with a water temperature of 62.4°C. Although no physico-chemical measurements were performed at the time of sampling, the environmental characteristics of the area can be derived from data collected in 2011 and published by Parikka et al. (2018). In the paper, they indicate a clearly alkaline pH (8.1–9.8), a moderate conductivity (265 µS/cm) and very high SO₄²⁻ (146–152 µmol L⁻¹) and Cl⁻ (613–630 µmol L⁻¹) values.

The species was so far not observed on other sub-Antarctic localities. Le Cohu and Maillard (1986, fig. 58 under the name *P. rivularis* Hustedt) observed the species in several rivers on Grand Terre, Iles Kerguelen, indicating that the species might have a broader distribution area on the archipelago thriving in mosses and algae in flowing waterbodies.

Discussion

Analysis of all *Pinnularia* species described from the sub-Antarctic region indicated several species that showed some similarities with the new *P. schoelynckiana*. Bourrelly and Manguin (1954) described *P. circumducta* Manguin from a peat sample. Although the authors indicated the species as being 'rare' in the sample, an attempt was made to analyse all slides made from the material. Unfortunately, specimens belonging to *P. circumducta* were never found (Van de Vijver et al. 2004b). Le Cohu (1981) illustrated valves presumably belonging to *P. circumducta* but careful analysis revealed the presence of spines at the apices and in the central area. The latter species was in 2004 described as *P. sofiae* Van de Vijver & Le Cohu (Van de Vijver et al. 2004b). *Pinnularia sofiae* clearly differs in its parallel striation, the presence of spines at the apices and in the central area and the broad rectangular fascia (Van de Vijver et al. 2004b), all features that have never been observed in *P. schoelynckiana*. The only illustration of *P. circumducta* is most likely fig. 74 in Le Cohu and Maillard (1986), although it could not be confirmed using the type material. *Pinnularia circumducta* shows a relatively similar valve outline, although the apices of *P. schoelynckiana* seem to be narrower than in *P. circumducta*. Important differences however are the presence of a longitudinal line on *P. circumducta*, as drawn by Manguin (Bourrelly and Manguin 1954, fig. 51) that is absent in *P. schoelynckiana* and a different striation pattern in the central area. In *P. circumducta*, the striae bordering the central area are hardly shortened whereas in *P. schoelynckiana*, the striae near the central area are gradually shortening. Finally, the terminal raphe fissures in *P.*

circumducta seem to be clearly sickle-shaped, terminating on the valve face whereas in *P. schoelynckiana* the terminal fissures are hooked and continue clearly onto the mantle.

Another sub-Antarctic taxon, *P. subantarctica* var. *elongata* (Manguin) Van de Vijver & Le Cohu, showing a similar valve outline, differs in having longitudinal lines on its striae and non-shortened striae bordering the central area (Van de Vijver, Frenot, and Beyens 2002). Le Cohu and Maillard (1986, fig. 58) illustrated a *Pinnularia* valve that seems to be identical to the new species and identified it as *P. rivularis* Hustedt, described from Java (Simonsen 1987). However, analysis of the type specimens of *P. rivularis* depicted in Simonsen (1987, p. 160, pl. 255, figs 3–5) revealed that the latter is entirely different and shows no similarity with the Kerguelen specimen illustrated by Le Cohu and Maillard (1986). Other similar *Pinnularia* taxa in the sub-Antarctic region could not be found.

Several other *Pinnularia* taxa worldwide show some similarity to the new *P. schoelynckiana*. These include *P. similis* Hustedt, *P. similiformis* Krammer, *P. diversa* Østrup and *P. lunata* Krammer & Lange-Bertalot.

Pinnularia similis was described by Hustedt from Java in 1934 (Schmidt 1934). Simonsen (1987, plate 244, fig. 5) illustrated the lectotype adding a second, morphologically rather different, specimen as isolectotype (plate 244, figs 3 & 4). The valve dimensions of both taxa are similar. The drawings in Schmidt (1934, pl. 385, figs 10–12) however show a more slender, linear-lanceolate valve outline, contrary to the more rhombic-lanceolate outline in *P. schoelynckiana*. Additionally, the change in stria orientation occurs in *P. similis* almost halfway between central area and apex whereas in *P. schoelynckiana*, this change is positioned much closer to the valve apices. The central raphe endings are also much closer together in *P. similis*, continuing further into the central area. In *P. schoelynckiana*, the central endings are rather distant and terminate just slightly beyond the last striae bordering the

central area. The striae are more geniculate in *P. schoelynckiana* whereas in *P. similis* they seem to be almost straight.

Pinnularia similis is a worldwide reported taxon. Unfortunately, most reports only mention the name lacking illustrations making it very difficult to verify whether the reported population/valves actually represent the true *P. similis*. A population from Uruguay (Metzeltin, Lange-Bertalot, and García-Rodríguez 2008) that was identified as *P. similis*, shows broader valves, a more undulating raphe and broadly rounded, subcapitate apices, making it less likely to be conspecific with *P. similis sensu stricto*. The Uruguayan population differs from *P. schoelynckiana* in having broader apices, a clearly undulating, lateral raphe and a smaller central area where a fascia is occasionally lacking (Metzeltin, Lange-Bertalot, and García-Rodríguez 2008, plate 172). Bourrelly and Manguin (1952, fig. 121) show in a sample from Guadeloupe, a more lanceolate (and clearly not linear) valve with narrow apices contrary to *P. similis* s.s. *Pinnularia similis* fo. *recta*, described from Guadeloupe in the same paper, is narrower than *P. schoelynckiana* with a strictly linear valve outline showing parallel, straight, never convex margins as is the case in *P. schoelynckiana* (Bourrelly and Manguin, 1952, fig. 122). Compère (1975, fig. 265) also shows a valve that is neither conspecific with *P. similis* (central area much larger, valve margins straight) nor with *P. schoelynckiana* (central area much larger, no shortened striae, valve margins never convex, apices too narrow). Other records such as Delgado and Souza (2007), Foged (1971), Frenguelli (1942, 1953), Fujita & Ohtsuka (2005), Guermeer (1954), Krasske (1943), Le Cohu and Maillard (1986), Souza and Senna (2009), Tynni (1976, 1991) show valves that should be distinguished from both *P. similis* and *P. schoelynckiana* based on valve outline, shape and size of the apices or shape of the central area. It is clear that a revision of all these *P. similis* populations will be needed to establish the correct biogeography of the latter species and that most of these observations are the result of a clear force-fitting of the (South) American,

African and European populations into *P. similis* from Java (Tyler 1996). *Pinnularia* aff. *similis* reported by Lange-Bertalot and Metzeltin (2009) from Panama shows some similarity with *P. schoelynckiana* but can be differentiated by a more undulating valve outline, a slightly larger central area and a clearly undulating raphe. Krammer (2000) separated smaller valves as *P. similiformis* that can be distinguished from *P. schoelynckiana* in having narrower valves (5.3–6.5 μm vs. 7.5–8.5 μm in *P. schoelynckiana*) and shorter, straight striae. *Pinnularia diversa* was described from the Färöes Islands (Østrup 1901) but is much smaller with narrower valves (max. width up to 6 μm) showing a very abrupt change in stria orientation in the middle between the central area and the apices (Krammer 2000). Finally, *Pinnularia lunata*, a species found in Siberia (Lange-Bertalot and Genkal 1999), shows typical depressions in the axial and central area that are absent in *P. schoelynckiana*. The Siberian species is also shorter but has a higher valve width (up to 9.5 μm) compared to *P. schoelynckiana* (Lange-Bertalot and Genkal 1999).

The description of the new *Pinnularia* species confirms the special interest of the hot spring area in Val Travers. In 2014, a new *Brachysira* species, *B. sandrae*, was described forming relatively large populations in the Val Travers samples, despite being absent in the rest of the sub-Antarctic region (Van de Vijver 2014). Only on the sub-Antarctic islands in the Pacific Ocean (Macquarie Island, Campbell Island), other *Brachysira* species were observed (Van de Vijver, unpubl. results). The samples in Val Travers also contain large populations of *Frustulia lebouvieri* Van de Vijver & Gremmen, a species described from the Prince Edward Islands (Van de Vijver and Gremmen 2006) and only also found on Ile Amsterdam (Chattová, Lebouvier, and Van de Vijver 2014).

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Bart Van de Vijver is a full-time researcher at the Meise Botanic Garden, Belgium, and a part-time professor at the University of Antwerp, Belgium. His research focuses mainly on the taxonomy, morphology and biogeography of Antarctic freshwater and terrestrial diatoms. He has been studying non-marine diatoms in various parts of the Antarctic region for more than 20 years. He has described almost 400 new taxa and revised an additional 250 taxa.

Contribution: identification of diatom species, discussion of results and writing and editing of the manuscript.

Pieter Scholberg is a master student at the University of Antwerp making his Individual Project at the Meise Botanic Garden, Belgium under supervision of B. Van de Vijver.

Contribution: identification and photographing of the species, discussion of results.

Marc Lebouvier is a research engineer at the CNRS (Centre National de la Recherche Scientifique). He carries out his research in the program 136 "Subantarctic biodiversity, effects of climate change and biological invasions on terrestrial biota" supported by the

French Polar Institute : field work and sampling at Iles Kerguelen in 2005, discussion of results and reviewing of the manuscript.

Contribution: field work and sampling at Iles Kerguelen in 2005, discussion of results and reviewing of the manuscript.

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Figure captions

Figures 1–19: *Pinnularia schoelynckiana* sp. nov. LM pictures taken from the holotype population (sample B-3) from Val Travers (Grande Terre, Iles Kerguelen). 1. Frustule in girdle view. 2–19. LM. Valve views. Scale bar represents 10 μm .

Figures 20–26: *Pinnularia schoelynckiana* sp. nov. SEM pictures taken from the holotype population (sample B-3) from Val Travers (Grande Terre, Iles Kerguelen). 20. External view of an entire valve. 21. Mantle view of an individual valve showing the large hyaline edge of the mantle. 22. External view of the central area. 23. External view of a valve apex showing the terminal raphe fissure. 24. Internal view of an entire valve. 25. Internal view of the central area with the interrupted raphe branches. 26. Internal view of a valve apex showing the helictoglossa. Scale bars represent 10 μm except for fig. 26 where scale bar is 5 μm .



