Morphology, ecology, taxonomy and biogeography of *Stauroneis pachycephala* P.T. Cleve (Bacillariophyta) and its transfer to the genus *Envekadea*

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Abstract

Stauroneis pachycephala was described in 1881 from the Baakens River, Port Elizabeth, South Africa. Recently, it was found during surveys of the MacKenzie River (Victoria, Australia), the Florida Everglades (USA), and coastal marshes of Louisiana (USA). The morphology, ecology, taxonomy and geographic distribution of this species are described in the present paper. This naviculoid species is characterised by lanceolate valves with a gibbous centre, a sigmoid raphe, an axial area narrowing toward the valve ends, and capitate valve apices. The central area is a distinct stauros that is slightly widened near the valve margin. The raphe is straight and filiform, and the terminal raphe fissures are strongly deflected in opposite directions. Striae are fine and radiate in the middle of the valve, becoming parallel and eventually convergent toward the valve ends. The external surface of the valves and copulae is smooth and lacks ornamentation. The observations show this species has morphological characteristics that fit within the genus *Envekadea*. Therefore, the transfer of *S. pachycephala* to *Envekadea* is proposed and a lectotype is designated.

Introduction

Recent revisionary efforts on the classification and phylogeny of diatoms have targeted the naviculoid diatoms and recognised the importance of valve ultrastructure, protoplast organisation, molecular sequences, ecological and geological ranges, sexual compatibility and biogeography in defining relationships and diversity within this heterogeneous group (Round & Sims 1981, Round et al. 1990, Mann 1999, Spaulding et al. 1999). Revisions have resulted in the resurrection of old or description of numerous new genera, split off from the catch-all genus *Navicula* Bory de St. Vincent (Round et al. 1990). The genus *Envekadea* Van de Vijver et al. was described to include naviculoid diatoms with a sigmoid raphe, non-porous copulae, and large, rectangular to polygonal areolae closed by external hymenes (Gligora et al. 2009). Members of this genus are distributed across a broad ecological spectrum from marine to oligotrophic freshwaters (Gligora et al. 2009). In the present paper, the morphological, ecological, and biogeographical analyses of *S. pachycephala* based on new collections from Victoria (Australia), Florida (USA), Louisiana (USA), and compare these with type material from South Africa were provided. Ultimately, the transfer of *S. pachycephala* to *Envekadea* is proposed and a lectotype is designated.

Materials and methods

The MacKenzie River is located on the northern slopes of the Grampians National Park in Victoria, south-east Australia. During this project, physical and chemical characteristics of the water, including temperature, pH, specific conductance and dissolved oxygen were measured *in situ* using a Horiba multimeter (Water checker U-10). Benthic diatom samples were collected from rocky substrates using standard methods (Stevenson & Bahls 2006). Then samples were digested in 10% H_2O_2 at 90°C on a hotplate for 2 hours, after which 2 drops of 10% HCl added. Samples were filled with distilled water and left to settle overnight, the supernatant was discarded, and this process repeated at least four times (Battarbee 1986). Diatoms were identified using a Nikon Eclipse 80i microscope and Philips XL30 field-emission scanning electron microscope (SEM).

Results and discussion

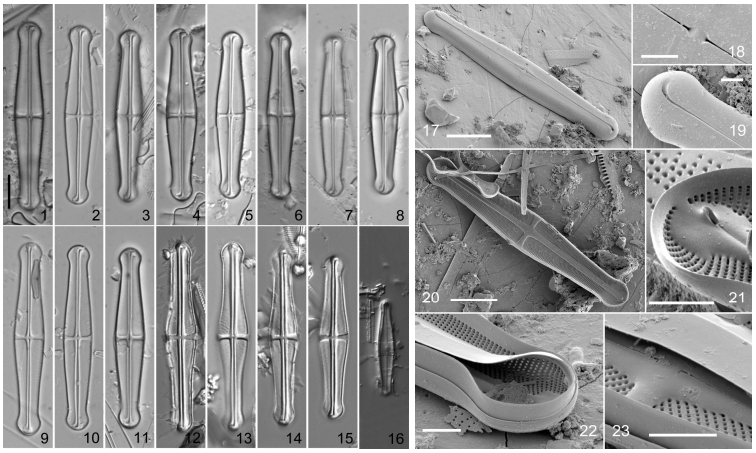
***Envekadea pachycephala* (P.T. Cleve) Atazadeh & Edlund comb. nov.**

Basionym: *Stauroneis pachycephala* P.T. Cleve 1881, p. 15; pl. 3,

Lectotype: Here designated as the specimen (Fig. 13) located 9.4 mm E x 5.8 mm S from the origin marked on slide ANSP Cleve & Møller 197.

Taxonomic remarks: : *Stauroneis pachycephala* was included in Cleve & Møller's (1878, and not 1879 as erroneously reported several times by various authors) list of species present in exsiccatum 197. However, this record must be considered as a *nomen nudum,* since the name was published without a valid description or diagnosis (ICBN Art. 38, McNeill et al. 2012. Therefore the valid description in Cleve (1881) is taken as the basionym. The morphological characteristics observed in *E. pachycephala*, such as the sigmoid raphe with the unilaterally deflected internal proximal ends, external distal raphe ends deflected in opposite directions and uniseriate, radiate striae occluded by external hymenes covering the entire valve, the internal structure of the areolae, and the unperforated copulae justify its transfer to *Envekadea*. The stauros, which is easily visible in the interior the valve of *E. pachycephala*, is absent in other known *Envekadea* species (Gligora et al. 2009, Graeff et al. 2013, Lee et al. 2013).

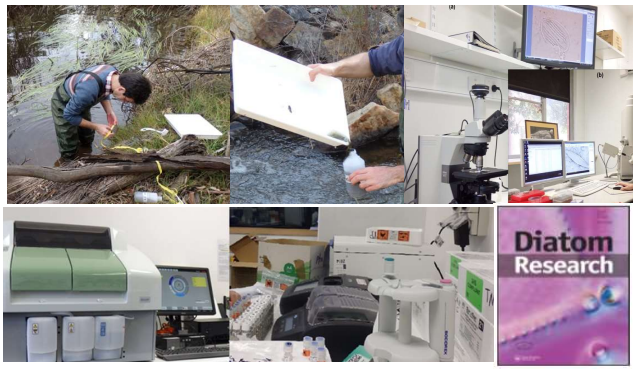
Ecology: The pH in the MacKenzie River where *E. pachycephala* was reported was circumneutral to acidic and the specific conductivity, suspended solids, and nutrient concentrations were low. During this survey in the MacKenzie River, *E. pachycephala* was found only in the upper reaches of the MacKenzie River, especially near the Wartook Reservoir. The most common diatom genera in the MacKenzie River were *Tabellaria* Ehrenberg ex F.T. Kutzing, *Navicula, Gomphonema* Ehrenberg, *Frustulia* Rabenhorst, *Brachysira* Kützing, *Brevisira* K. Krammer, *Eunotia*, and *Neidium* E. Pfitzer. The relative abundance of *E. pachycephala* was low (3-4%).



Figs 1-16. *Envekadea* species, light micrographs, DIC, scale bar = 10 µm. **Figs 1-8**. *Envekadea pachycephala* MacKenzie River, Wartook Outlet, Victoria, Australia (ANSP GC40128, CANA 87195, BR-4323). **Figs 9-11**. *Envekadea pachycephala* Wartook Reservoir, Victoria, Australia (ANSP GC40129, BR-4324). **Figs 12-15**. *Envekadea pachycephala*, Cl. & Møller exsiccatum Nr. 197 (ANSP Cleve & Moller 197), South Africa, Cape of Good Hope, Baakens River, Port Elizabeth. **Fig. 13**. Lectotype specimen. **Fig. 16**. Isotype slide of *Stauroneis pachycephala* var. *alaskana* Foged (1981) from ANSP GC64419 (Kuzitrin Lake, Alaska); this taxon belongs in the genus *Caloneis*. **Figs 17-23**. *Envekadea pachycephala*, MacKenzie River, Australia. SEM. **Fig. 17**. External valve view. **Fig. 18**. Central part of the valve with expanded proximal raphe ends, external view. **Fig. 19.** External distal raphe end. **Fig. 20**. Internal valve view. **Fig. 21**. Valve apex showing distal raphe end and helictoglossa**. Fig. 22**. Internal view of valve end showing unornamented valvocopula. **Fig. 23**. Central part of the valve with unilaterally deflected proximal raphe ends, internal view. Scale bars = 10 µm (Figs 17, 20) and 2 µm (Figs 18, 19, 21-23).

Envekadea pachycephala (formerly known as *Stauroneis pachycephala*)

Author (year)	Length (µm)	Width (µm)	Striadensity (#/10 µm)	Habitat	Locality
Cleve *et* Moller 1881	44.8-60.0	8.0-10.0	24.4-29.43	Brackish	S. Africa
Cleve 1894	40-55	7-9	29	Brackish	Tasmania, S. Africa
Cleve-Euler 1953	40-55	7-9	29	Fresh-brackish	Southern Hemisphere, Sweden
Hustedt 1959	40-60	7-9	30	Brackish	Tasmania, S. Africa
Foged 1976	35-41	7-8	30-35	Halophilous, alkaliphilous	Sri Lanka
Foged 1978	35	6.5	30	Mesohalobous, alkaliphilous	NSW, QLD
Foged 1979	46	7	-	Oligohalobous, alkaliphilous	New Zealand
John 1983	36-40	6-7	30	Freshwater	Western Australia
Foged 1984	40	8	dense	Oligo- to mesohalobe, alkaliphile	Cuba
Vyverman 1991	44-45	7.9-8.1	28	Mesohalobous, alkaliphilous	PNG
Gell & Gasse 1994	40-60	7-9	30	Freshwater	Victoria
Hodgson 1995	52.5	7.7	-	Fresh-brackish	Tasmania
Hodgson et al. 1997	33	5	30	Brackish	Tasmania
(this study)	43.1-58.0	7.0-9.0	27.0-30.3	Freshwater	Victoria, Australia
(this study)	38.8-45.6	6.9-7.8	27.8-29.4	Freshwater, alkaline	Florida
(this study)	34.8-50.3	7.0-8.3	26.3-30.3	Fresh-brackish	Louisiana



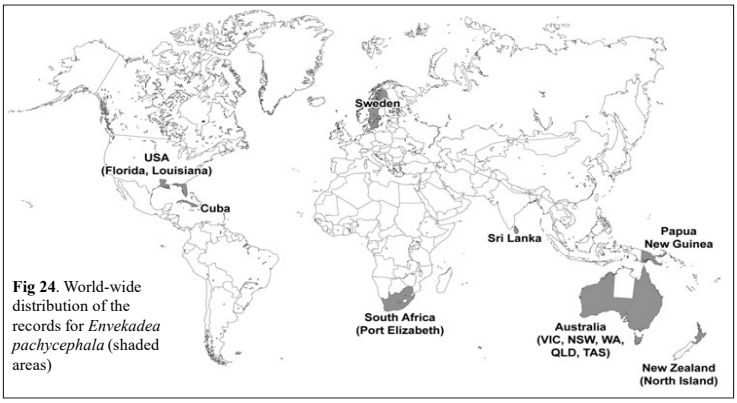


Fig 24. World-wide distribution of the records for *Envekadea pachycephala* (shaded areas)