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***Aulacoseira stevensiae* sp. nov. (Coscinodiscophyceae, Bacillariophyta), a new diatom from Ho Ba Bê, Bac Kan Province, Northern Việt Nam**

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Abstract

A new species of *Aulacoseira* Thwaites is described from piston core samples from Ho Ba Bê in the karst region of northern Việt Nam. Although it closely resembles *Aulacoseira subborealis* (Nygaard) Denys, Muylaert & Krammer, *A. stevensiae* Weide sp. nov. is designated a new species based mainly on morphological differences in the spines, including invariably inclined spines that are rounded, differences in the Ringleiste, areola pattern and overall size. *Aulacoseira stevensiae* is present throughout a core that spans the last 500 years. It was a major component of the diatom community, but the populations have recently decreased, possibly being out-competed by *Discostella* Houk & Klee and *Cyclotella* (Kützing) Brébisson species.

Keywords: separation spine, Ringleiste, karst, *Aulacoseira subborealis*, centric diatom

Introduction

Species of the genus *Aulacoseira* Thwaites are important trophic indicators in freshwater systems, making them useful tools for environmental and paleoenvironmental studies. They often dominate the phytoplankton in eutrophic lakes and rivers (Denys et al. 2003). For example, *A. granulata* (Ehrenberg) Simonsen has long been known to favour eutrophic lakes (Hall & Smol 1999, Denys et al. 2003), while *A. subarctica* (O. Müller) Haworth is known to prefer mesotrophic waters (Reynolds 1998). In addition, members of this genus have been used to reconstruct pH change over time (Lotter et al. 2010). This heavily silicified group requires substantial turbulence in the water column to stay afloat (Lund 1954, Bradbury 1975, Round et al. 1990). Bennion et al. (2010) also note that some *Aulacoseira* species have evolved resting stages, allowing cells to lie dormant until turbulence resumes. These properties make *Aulacoseira* a good proxy for water movement and lake stratification.

Aulacoseira was originally established in 1848 by Thwaites (Siver & Kling 1997). Most of the species currently assigned to *Aulacoseira* were originally placed in *Melosira* Agardh and later transferred to the former genus by Simonsen (1979) based on the presence of a collum, a hyaline area on the proximal edge of the valve mantle. As in many diatom genera, *Aulacoseira* specimens have mostly been identified and described using light microscopy, precluding the identification and description of ultrastructural elements that may differ between species. Because they are good indicators of present and past environmental condi-

tions, a taxonomy that includes ultrastructural characteristics is necessary to identify species and interpret their environment properly (Siver & Kling 1997).

A new species of *Aulacoseira* is described from piston core samples from Ho Ba Bê, a lake in the karst region of northern Viet Nam. While it closely resembles *A. subborealis* (Nygaard) Denys, Muylaert & Krammer in certain features, significant differences in the morphology call for its distinction from *A. subborealis* at the species level. These differences are visible in the light microscope in specimens where spines are preserved; thus, this new species can be clearly separated from *A. subborealis*.

Materials and methods

Location

Ho Ba Bê (N 22° 26', E 105° 35') is located in Bac Kan Province, Việt Nam, 254 km north of Hanoi (Figures 1, 2). It occupies a narrow north-south trending valley bordered by mountains on the east and west. The lake basin is approximately 8 km long and 800 m at its widest point. The lake surface is at an elevation of 178 m asl. The average depth is 20 m, with a maximum depth of 29 m. Three sub-basins, Pe Lam (north), Pe Lu (central), and Pe Leng (south), comprise a total area of 460 km². Input into the lake is via three rivers: Tà Han, Bo Lù, and Cho Lèng. Outflow is to the Nang River in the north basin (St-Onge et al. 2007). The presence of a sill at the drainage site may impede outflow if the water level drops significantly. Although the region is dominated by karst lithology, St. Onge et al. (2007) reported shale and granite in the surrounding catchment.

Figure 1. Map of Viet Nam and location of Ho Ba Bê.

Diatom samples

Specimens were obtained from a Livingstone Piston core (BBNB04), 2.12 m in length, collected from the Pe Lam (north) basin at a depth of 14 m in 2004. Preliminary sedimentation rates, based on ^{14}C dates and ^{137}Cs spikes, suggest that BBNB04 was deposited from the late 1500s until sometime after AD 1986. A short core from the Pe Leng (south) basin (BBSB04) and water samples also yielded specimens. Contiguous samples were collected from the BBNB04 and digested with 30% H_2O_2 and 30% HCl. Clay was removed via suspension with 1% reagent-grade sodium metaphosphate solution. Slides were prepared using Cargille Meltmount™ mounting medium (refractive index = 1.704). A Nikon OPTIphot microscope equipped with a Nikon universal condenser (Achr-Apl 1.4) with phase contrast and a Plan 100/1.25 oil DL objective was used for identification. Additional imaging was carried out on a FEI Quanta™ 200 scanning electron microscope.

Results

Aulacoseira stevensiae Weide sp. nov. (Figures 3–16)

Description. Valves are cylindrical with diameters between 3.5–7.0 μm , with the majority falling between 5 and 6 μm (Figures 3–10). Chains of 2–10 valves have been observed. Valve face is flat or slightly concave with many areolae (Figure 11). The areolae on the valve face are round, diminishing in size towards the centre and are found mostly towards the edge of the valve face, with fewer areolae in the centre. Mantle height ranges from 2.0 to 3.85 μm . The mantle height to diameter ratio is 0.40–0.55, with the average being 0.47. The man-

Figure 2. Map of Ho Ba Bê. X represents location of sediment core.

tle wall is slightly convex with the greatest width being halfway between the spines and the collum. Pervalvar rows on the mantle are inclined, and rarely curved, most commonly to the right (i.e., dextrorse) (Figure 12). Areola density on the mantle is 20–25 areolae/10 μm . Each peralvar row is made up of alternating rows of five and six areolae (Figures 12–13). There are 22–30 peralvar striae per 10 μm . Rounded knobs are present on the peralvar ribs such that each areola is surrounded by four knobs. A collum is present on each valve and is between 0.57 and 0.75 μm high, with a collum to mantle height ratio of 0.20–0.27. The collum is ornamented with ridges oriented along the peralvar axis (Figures 12–13). Each spine arises from two peralvar ribs and tapers towards the tip (Figure 13). Spines are almost always inclined to the right (i.e., dextrorse) (Figures 11–13), fitting into a paired groove on the sister valve. However, several specimens with sinistrorse spines have been observed at a similar angle (Figure 14). Spines are curved slightly inwards and their ends are rounded (Figures 13–14). Spines are all of equal length. Transition from the valve face to the mantle is abrupt. A Ringleiste is present and sits perpendicular to the mantle wall. Its width is between 1.5 and 2.0 μm . The Ringleiste is thicker at its interior edge and appears to be bulbous in cross-section (Figures 15, 16).

Differential diagnosis. This species differs from *A. subborealis* by having inclined spines with round ends and a Ringleiste width to valve diameter ratio of 0.3, compared to 0.23–0.25 for *A. subborealis*. In addition, the spines always arise from two peralvar ribs, whereas in *A. subborealis* they arise from either two or three.

Holotype. Slide no. 223044, housed in the diatom collection at California Academy of Sciences, San Francisco, CA, USA (Figures 3–5, BBNB04, Drive 2, 37.5–38.0 cm depth).

Figures 3–10. **Figures 3–5.** Holotype of *A. stevensiae*. **Figures 6–10.** *A. stevensiae* specimens from throughout the core. Scale bar = 5 μ m (Figures 3–5, g); 10 μ m (Figures 6–8, 10).

Type locality. Ho Ba Bê, Bac Kan Province, Việt Nam (22° 26' N, 105° 35' E). Cores (BBNB04 & BBSB04) collected January 2004 by Lora Stevens, Matt Landon, Vu The Long.

Habitat. Tropical freshwater, dominated by bicarbonate with a pH of ~8–9.5.

Etymology. The specific epithet is chosen in honour of Dr. Lora Stevens for her superior mentorship.

Co-occurring species. *Aulacoseira granulata*, *A. crassipunctata* Krammer, *A. ambigua* (Grunow) Simonsen, *Cyclotella delicatula* Hustedt, *C. ocellata* Pantocsek, *Discostella asterocostata* Lin, Xie & Cai, *D. stelligera* (Cleve & Grunow) Houk & Klee, *Gyrosigma procerum* Hustedt, *Punctastriata linearis* D.M. Williams & Round, *Punctastriata cf. mimetica* Morales, *Punctastriata cf. ovalis* Williams & Round, *Staurosira construens* Ehrenberg, *Staurosira cf. venter* (Ehrenberg) Kobayasi, *Staurosirella cf. pinnata* (Ehrenberg) Williams & Round, *Thalassiosira rudis* Tremarin, Ludwig, Becker & Torgan.

Discussion

Aulacoseira stevensiae is present throughout BBNB04 (Figure 17) and has been confirmed as present, but not quantified, in the south basin (BBSB04). With preliminary

dating, this indicates that *A. stevensiae* has existed for at least half a millennium, from the late 1500s to the end of the twentieth century, possibly longer. In addition, specimens were present in water samples from the north basin and the Nang River (upriver from the lake, collected in 2004) when the cores were taken, indicating that it was extant in 2004. *Aulacoseira stevensiae* is one of the dominant species throughout the core. However, in recent times, 0–3 cm depth, *A. stevensiae* numbers have declined dramatically, and the species is overshadowed by other planktonic species, such as *T. rudis*, *C. ocellata*, and *C. delicatula*. The water quality of the lake in 2004 is shown in Table 1. In recent times, *A. stevensiae* has been found in slightly basic (lacustrine) to more strongly basic (riverine) waters dominated by bicarbonates and planktonic species (mainly *Cyclotella* (Kützing) Brébisson and *Discostella* Houk & Klee).

Aulacoseira stevensiae closely resembles *A. subborealis* (Denys et al. 2003) in valve structure and morphology, but the differences between them are deemed significant enough to warrant a new species. It should be noted here that *A. subborealis* may be a synonym of *A. pusilla* (Meister) Tuji & Houki (Tuji & Williams 2006). They examined *A. pusilla* isotype material and determined that specimens from Katata Lagoon, Japan also belonged to *A. pusilla*. However, this paper did not include a reanalysis of *A. subborealis*.

Figures 11–16. **Figure 11.** Valve view of *A. stevensiae*. Valve face is flat with many areolae throughout. **Figure 12.** Girdle view of *A. stevensiae*. Mantle striae are inclined or curved, usually to the right. **Figure 13.** *Aulacoseira stevensiae* spines. Note the spines are inclined to the right. **Figure 14.** Sinistrorse specimen of *A. stevensiae*. Note that the mantle striae are still dextrorse, while the spines are sinistrorse. **Figures 15–16.** Views of the Ringleiste of *A. stevensiae*. Note that the inner rim of the Ringleiste is thicker than the rest. Scale bars = 2 μ m (Figures 11–13); 5 μ m (Figures 14–16).

Table 1. Water quality data for Ho Ba Bê, Việt Nam.

	Depth (m)	pH	NO ₃ (mg L ⁻¹)	SO ₄ (mg L ⁻¹)	HCO ₃ (mg L ⁻¹)	Ca (mg L ⁻¹)	Mg (mg L ⁻¹)	Na (mg L ⁻¹)	K (mg L ⁻¹)	Cl (mg L ⁻¹)
North ^a Basin	1	8.2	5.3	7.1	130.7	43.6	3.2	4.4	2.6	1.6
	15	n.d.	n.d.	6.1	166.4	46.9	3.3	3.9	2.9	1.6
	22	n.d.	n.d.	5.0	186.4	49.1	3.5	4.2	3.4	1.6
South ^b Basin	1	8.3	5.4	7.1	133.7	42.8	3.2	4.2	2.9	2.0
	12	n.d.	5.3	6.9	135.6	43.0	3.1	4.3	2.8	1.6
Nang ^c River	0	9.6	5.4	8.5	165.8	40	3.9	3.8	2.8	1.5

a. N 22.436, E 105.614722.

b. N 22.398611, E 105.629083.

c. N 22.447167, E 105.607056.

For locations of samples, see Figure 2.

n.d. = no data.

Samples taken on January 4, 2004.

Tuji & Houki's (2004) analysis of the *A. subarctica* complex, which established the new combination of *A. pusilla* for specimens with areolae on the valve face, did not include specimens of *A. subarctica* f. *subborealis*, a synonym of *A. subborealis*. At this time, *A. subborealis* is still listed as a valid taxon and is not listed as a synonym of *A. pusilla* (Potapova 2010, Fourtanier & Kociolek 2015, Guiry & Guiry 2015). As such, I compare *A. stevensiae* to *A. subborealis*, which includes a larger morphological and geographic range.

Aulacoseira stevensiae differs notably in that it has spines that are rounded at the edges and predominantly inclined towards the right (Figures 12–14), whereas the spines of *A. subborealis* are robust and pointed. The spines always arise from two pervalvar ribs, unlike those of *A. subborealis*, which originate from 2 or 3 ribs. Each spine is paired with a groove in the sister valve, possibly functioning more as separation spines. In addition, the pervalvar striae are composed of alternating rows of five and six areolae (approx. 20–25/10 µm). While the density of areolae may fluctuate, the actual pattern of areolae is always alternating rows of five and six within the Ho Ba Bê population.

The presence of a Ringleiste is reported in both species. Krammer (1991) defines the Ringleiste as 'either a solid ridge or a ring-like (annulate) wall, projecting inwards from the collum.' *Aulacoseira stevensiae* has a Ringleiste that is 1.5–2.0 µm wide. The average Ringleiste width to valve diameter ratio is approximately 0.3, compared to the smaller 0.23–0.25 ratio of *A. subborealis*. Denys et al. (2003) note that the inner margin of the Ringleiste in *A. subborealis* is T-shaped in cross-section, whereas the inner margin of the Ringleiste appears to be thickened, possibly bulbous in cross-section in *A. stevensiae* (Figures 15–16). Unfortunately, no cross-section view of the Ringleiste has yet been found for *A. stevensiae*.

Other differences, though more subtle, separate *A. stevensiae* from *A. subborealis*. The ranges of the valve diameter and mantle height of *A. stevensiae* (3.5–7.0 µm and

Figure 17. Variation in relative abundance of *A. stevensiae* down core. Preliminary ¹⁴C- and ¹³⁷Cs-based dates are shown.

2.0–3.85 µm, respectively) are smaller than those of *A. subborealis* (5.5–9.0 µm and 2.2–4.5 µm) (Denys et al. 2003), although there is overlap at the lower end of the *A. subborealis* range. The mantle height to diameter ratio in *A. stevensiae* is ~0.50, whereas *A. subborealis*'s mantle height to diameter ratio was reported by Krammer & Lange-Bertalot (2008) as ~1.0, and Denys et al. (2003) reports it as more variable, 0.39–0.75. *Aulacoseira stevensiae*'s ratio is much more constrained than the published data for *A. subborealis*, although only one site has thus far been described.

Conclusion

Aulacoseira stevensiae resembles *A. subborealis* more than other *Aulacoseira* species, but there are several significant differences, most notably the presence of inclined separating spines and a Ringleiste that is wider relative to its diameter. Because of these differences in spine morphology and the associated lack of variability within this character state, our specimens should be assigned to a new species.

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