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Ecology and distribution of *Aulacoseira* species (Bacillariophyta) in tropical reservoirs from Brazil

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Ecological preferences and distribution of *Aulacoseira* species in southeastern Brazilian reservoirs with varying trophic states were studied. One hundred and fourteen plankton samples (winter and summer) from 57 sites located in 16 reservoirs were analysed. Ten water quality parameters were measured. Ten *Aulacoseira* species were identified using light, scanning and transmission electron microscopy, and new information on their ecological preferences is provided here. Our results indicate that trophic gradient is the main driver of species distribution. Principal components analysis and calculation of weighted average nutrient optima revealed three indicator taxa, *Aulacoseira tenella* characteristic for oligotrophic waters and two varieties of *Aulacoseira granulata* (nominate and var. *angustissima*) typical for eutrophic reservoirs. This is the first ecological study of *Aulacoseira* in Brazil, adding information on the distribution of this genus in the tropics, and highlighting the need for species-level identification and regional studies to improve the use of diatoms in water quality assessment.

Keywords: *autecology, bioindication, centric diatoms, South America, taxonomy, weighted average*

Introduction

Aulacoseira Thwaites is a widespread genus inhabiting lacustrine and lotic freshwaters, where it is an important component of the phytoplankton developing in various trophic conditions (Denys et al. 2003). Based on a review of the literature, Edgar & Theriot (2004) reported approximately 60 species.

Although *Aulacoseira* species have been widely studied, mainly in temperate regions (e.g., Krammer & Lange-Bertalot 1991, Siver & Kling 1997, Houk 2003, Houk & Klee 2007, Potapova et al. 2008, Tuji 2010), the genus remains poorly known in South America. Only Oliveira & Steinitz-Kannan (1992), Sala et al. (1999, 2002, 2008), Metzeltin & Lange-Bertalot (2007), Tremarin et al. (2011, 2012, 2013a, b, 2014a, b), Dunck et al. (2012), Wetzel et al. (2014) and Morales et al. (2015) include some considerations of selected species occurring in tropical South America. In Brazil, 25 species have been reported (Tremarin et al. 2014a, b), 8 of which were originally described from Brazilian material (Hustedt 1965, Tremarin et al. 2012, 2013a, 2014a, b). Most taxa were recorded in floristic studies based on light microscopy (LM), without a more detailed analysis of the frustule (e.g., Silva et al. 2010, Nardelli et al. 2014, Faustino et al. 2016). In ecological studies, frequently reported taxa correspond to widely distributed ones, such as those in the *Aulacoseira granulata* (Ehrenberg) Simonsen species complex and *A. ambigua* (Grunow) Simonsen (e.g., Nogueira 2000, Raupp et al. 2009, Costa-Böddeker et al. 2012).

Autecological information for *Aulacoseira* is fragmented and very scarce worldwide, particularly for tropical and subtropical regions. In Brazil, a few ecological aspects of *Aulacoseira italica* (Ehrenberg) Simonsen were investigated by Nakamoto et al. (1976), Lima et al. (1979, 1983) and Marins (1978), and the tolerance of *A. granulata* to copper sulphate, an algicide used to control cyanobacterial blooms, was demonstrated in an ecotoxicological study (Viana & Rocha 2005). Nevertheless, the study of ecological preferences and distributions, based on sound taxonomy, is critical for the successful use of diatoms in

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water quality bioassessment (Ponader et al. 2007). This is particularly relevant in the context of the growing threats to freshwater ecosystems by human impact (Dundgeon et al. 2006, Smith et al. 2006).

This study uses a large tropical reservoir dataset covering a wide range of trophic states to calculate optima for *Aulacoseira* taxa. The goal is to describe the diversity of species of *Aulacoseira* in southeastern Brazil and to improve understanding of their ecology and distribution patterns.

Material and methods

The study includes three drainage basins in the State of São Paulo, southeastern Brazil (Fig. 1), and is part of a larger research effort, the AcquaSed Project. This project aims to establish baseline conditions and to reconstruct the anthropogenic impact history in the Guarapiranga Reservoir, focusing on the ecological quality of the water supply reservoirs of the Alto Tietê and surrounding basins, and to enhance the use of diatoms as bioindicators in tropical reservoirs. The climate is tropical, dry in winter and rainy during summer, the average temperature for the hottest month is above 22°C, and for the coldest month is below 18°C (CEPAGRI 2015). The drainage basins include protected and highly urbanized reservoirs encompassing a large gradient of trophic states (from oligo- to hyper-eutrophic conditions). This study was conducted on 16 reservoirs with different uses (recreational, electricity generation, navigation and public water supply), ranging from shallow to deep (maximum depth from 2 up to 33 m) and from small to large (surface area from 0.2 to 241.3 km²). One to eight sampling sites per reservoir were chosen, considering maximum depth, size and main water inputs (main streams).

The sampling sites are located between 22.5°–24.3°S and 45.7°–48.5°W. In total, 57 sites were sampled during austral winter and summer, from 2009 to 2014 (114 samples). Integrated plankton samples were collected with a van Dorn sampler along vertical profiles (subsurface, mid-depth, and 1 m above the sediments). Temperature, pH and conductivity were measured in the field using standard electrodes (Horiba U50). Water chemistry measurements were conducted following American Public Health Association protocols (APHA 2005). Water samples filtered through Whatman GF/F membrane filters were used for measuring, ammonium ($N–NH_4$), nitrate ($N-NO_3^-$), nitrite ($N-NO_2^-$), soluble reactive phosphorus

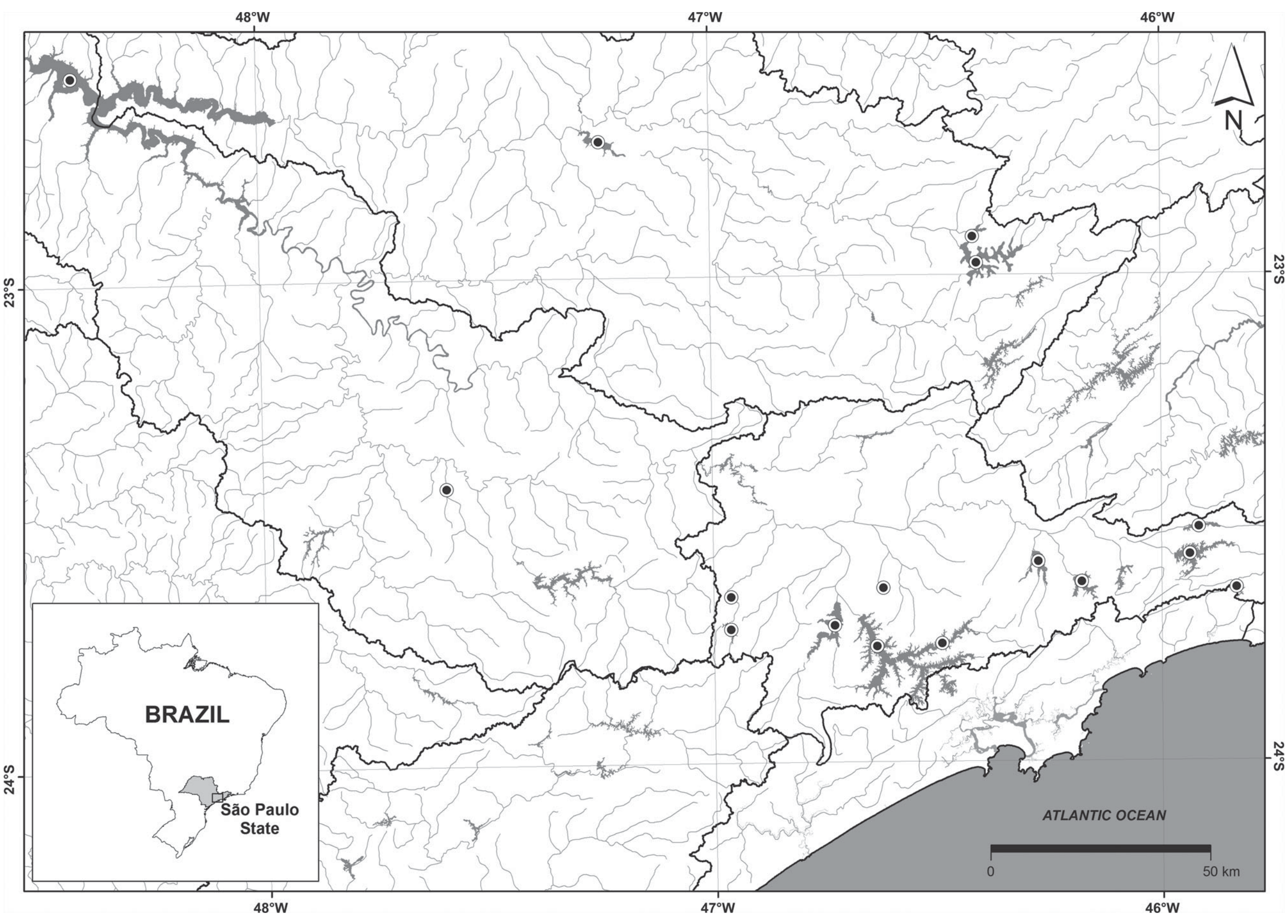


Fig. 1. Map of the study area with the locations of the 16 sampled reservoirs.

Table 1. Summary of water quality data for the 57 studied sites (water column mean).

	Summer			Winter		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Temperature (°C)	24.8	28.9	19.8	17.9	21.8	12.5
pH	6.7	8.5	5.3	6.8	8.7	5.1
Conductivity (μS cm^{-1})	93.6	383.0	10.4	137.5	487.7	10.4
Alkalinity (mEq L^{-1})	0.482	1.546	0.051	0.527	1.861	0.051
TN (μg L^{-1})	1415.7	10652.1	88.5	1373.2	9767.0	178.1
DIN (μg L^{-1})	654.2	5386.2	13.0	840.6	7728.1	23.0
TP (μg L^{-1})	58.2	381.3	4.0	55.9	502.9	4.0
SRP (μg L^{-1})	18.9	163.6	2.6	26.4	446.0	4.0
SRS (mg L^{-1})	2.8	6.5	1.1	2.7	6.2	0.6
Chlorophyll *a* (μg L^{-1})	20.6	149.9	0.5	22.1	175.9	0.5

Note: TN: total nitrogen, TP: total phosphorus, DIN: dissolved inorganic nitrogen, SRP: soluble reactive phosphorus, SRS: soluble reactive silica.

($P–PO_4$), and soluble reactive silica (SRS). Dissolved inorganic nitrogen (DIN) was calculated as the sum of ammonium, nitrate and nitrite. Unfiltered samples were used for alkalinity, total nitrogen (TN) and total phosphorus (TP) determinations. Chlorophyll *a*, corrected for phaeophytin, was measured using 90% ethanol extraction (Sartory & Grobbelaar 1984). A summary of data for the selected water quality variables is shown in Table 1.

For diatom analyses, samples were digested according to standard procedures (Battarbee et al. 2001) using 35% by volume H_2O_2 and 37% HCl. Slides were mounted with NAPHRAX, and LM observations, measurements and micrographs were obtained using a Zeiss Axioskop 2 plus, equipped with a DC500 high-resolution digital camera, under 1000 × magnification. Subsamples were cleaned using the method of Hasle & Fryxell (1970), dried on aluminium stubs and coated with gold at 1 kV for 5 min in a Balzers SCD030 sputter coater. Scanning electron microscope (SEM) observations were performed with a JEOL JSM 6360LV operated at 15 kV and 8 mm working distance. Subsamples were also dried on grids (300 mesh) for TEM observations with a JEOL JEM 1200EX-II operated at 80 kV. At least 400 valves were counted per slide at 1000 × magnification. Samples were deposited at the 'Herbário Científico do Estado Maria Eneyda P. Kauffmann Fidalgo', São Paulo, Brazil.

Species abundances were expressed as a percentage of the total diatom counts in each sample. Optima for temperature, pH, conductivity, alkalinity, soluble reactive phosphorus, DIN, TP and TN were calculated as weighted average values (ter Braak & van Dam 1989) based on species relative abundances.

We analysed the distribution of *Aulacoseira* species with principal components analysis (PCA) followed by environmental factor fitting, which projects passive environmental variables (chlorophyll *a*, conductivity, pH, TN, TP and water temperature) onto the PCA diagram without any constraints, allowing *post hoc* interpretation of ordination axes (Bocard et al. 2011). The environmental variables (except pH) were log-transformed ($\log x + 1$) and species abundances were Hellinger-transformed in order to approximate more closely the linear relationship assumed by PCA (Legendre & Gallagher 2001). For this analysis, we considered species with relative abundance equal to or greater than 5%. Diatom names were coded according to the OMNIDIA software (Lecointe et al. 1993). All analyses were performed using R version 3.1.3 (R Core Team 2015) and the 'vegan' package (Oksanen et al. 2013).

Results and discussion

Morphometric data for the studied *Aulacoseira* species are presented in Table 2. Figure 2 shows the relative abundances of the *Aulacoseira* species (described below) in relation to water temperature, pH, conductivity and alkalinity ranges. Figure 3 shows relative abundances of the taxa in relation to soluble reactive phosphorus ($P–PO_4$), DIN, TP and TN concentrations. Weighted average optima are shown for each taxon and each environmental variable.

Aulacoseira ambigua (Grunow) Simonsen (Figs 4–11)

Morphology: *Aulacoseira ambigua* differs from other *Aulacoseira* species by the presence of a hollow and narrow ringleist in the valve mantle. Besides this characteristic, the species is characterized by forming long chains (observed in non-oxidized material) in which frustules are linked by many small spines, obliquely curved striae on the mantle and a narrow ringleist (Tremarin et al. 2013a).

Ecology and distribution: This is a cosmopolitan species, commonly found in lotic and lentic environments from different regions of Brazil (Tremarin et al. 2013a) and the world (Guiry & Guiry 2014). It is found in oligotrophic to eutrophic waters (van Dam et al. 1994, Stenger-Kovacs et al. 2007), but prefers nutrient-rich waters (Houk 2003, Taylor et al. 2007). This species is also reported during

Table 2. Frequency of occurrence, abundance (%) and morphometric data for studied *Aulacoseira* species.

Taxa	Occurrence (%)	Maximum abundance	Mean abundance	*D* (µm)	MH (µm)	Ratio (MH/*D*)	Striae (in 10 µm)	Areolae (in 10 µm)
A. ambigua	77.2	67.7	7.0	3.7–11.1	5.6–13.1	0.6–2.7	14–20	14–18
A. brasiliensis	16.7	12.9	0.8	14.0–16.0	4.0–5.0	0.2–0.3	13–16	16–20
A. calypsi	7.9	16.4	0.6	8.4–12.0	3.1–6.1	0.3–0.6	14–26	16–18
A. granulata var. *angustissima*	45.6	61.1	3.4	2.1–5.1	6.0–18.5	1.5–7.3	12–16	10–15
A. granulata var. *australiensis*	41.2	11.9	1.3	4.3–19.3	8.5–23.1	0.6–2.7	8–18	7–13
A. granulata var. *granulata*	93.0	79.2	13.1	5.0–18.1	7.8–22.5	0.6–4.2	8–14	7–13
A. herzogii	15.8	23.3	0.8	5.0–12.0	6.0–30.0	0.9–5.8	24–27	Inconsp.
A. laevissima[a]	–	–	–	3.5–8.9	2.0–3.7	0.3–0.9	24–28	Inconsp.
A. pusilla[a]	–	–	–	4.0–6.9	1.8–2.7	0.7–4.0	20–24	Inconsp.
A. tenella	81.6	80.5	11.8	4.6–6.6	1.1–2.2	0.2–0.4	20–28	2–3

Note: *D*: valve diameter, MH: mantle height.
[a]Very scarce taxa, observed in qualitative analysis.

water mixing and low light conditions (Houk 2003, Taylor et al. 2007). In our data set, it was the third most frequent species, achieving high maximum abundances (Table 2). It was more abundant in colder (winter), slightly acid (Fig. 2) and, contrary to reports in the literature (Houk 2003, Taylor et al. 2007), in mesotrophic waters (Fig. 3). This species usually co-occurred at lower abundances with the nominate variety of *A. granulata* var. *granulata*, which had a preference for eutrophic waters (Fig. 3).

Aulacoseira brasiliensis Tremarin, Torgan et Ludwig (Figs 12–21)

Morphology: The population of *A. brasiliensis* resembles type material of the species (Tremarin et al. 2012). The obovate marginal spines and the double row of sessile rimoportulae in the mantle differentiate *A. brasiliensis* from other morphologically similar taxa, such as *Aulacoseira muzzanensis* (Meister) Krammer and *Aulacoseira agassizii* (Ostenfeld) Simonsen (Tremarin et al. 2012). This diatom forms short chains with frustules linked by several ovate-attenuate spines, and has a shallow mantle, undeveloped ringleist, and completely areolated valve face and mantle with straight rows of conspicuous areolae. Connection valves have not been described for this taxon.

Ecology and distribution: Thus far, this species has only been reported from tropical and subtropical regions of Brazil (Tremarin et al. 2012). Tremarin et al. (2012) reported it from warm (21.3–29.9°C), slightly acidic to neutral pH, and low conductivity (6.3–26 μS cm^{-1}) waters. *Aulacoseira brasiliensis* in our material was rare and always at relatively low abundance (Table 2). Sometimes it co-occurred with *Aulacoseira tenella* (Nygaard) Simonsen, but always at lower abundances. *Aulacoseira brasiliensis* was mainly found in colder, oligotrophic, low conductivity and slightly acidic waters (Figs 2–3), corroborating literature reports for this species.

Aulacoseira calypsi Tremarin, Torgan et Ludwig (Figs 22–33)

Morphology: This taxon resembles *A. brasiliensis* in its mantle striation pattern, but differs in spine morphology, distribution of areolae on the valve face and position of the rimoportulae (Tremarin et al. 2013b). It is characterized by long filaments, spathulate linking spines, obovate to conic separation spines, a variably ornamented valve face, straight striae on the mantle and a narrow ringleist (Tremarin et al. 2013b). The sessile rimoportulae, arranged in an irregular ring near the ringleist are diagnostic for this species.

Ecology and distribution: This species was described from a meso-eutrophic lake with high water temperature (30.8°C) and neutral pH in the State of Pará, northern Brazil (Tremarin et al. 2013b); this is the second report of the taxon. In our study, it was the least abundant and frequent species (Table 2), occurring in oligo to mesotrophic waters, rarely in hypereutrophic conditions, and at relatively low water temperatures (Figs 2–3). It prefers mesotrophic, slightly acidic and low conductivity waters. This taxon co-occurred with *Aulacoseira herzogii* (Lemmermann) Simonsen, which has similar ecological preferences.

Aulacoseira granulata (Ehrenberg) Simonsen var. _granulata_ (Figs 34–37)

Morphology: This taxon differs from other species in the genus by the presence of one or two long separation spines, a coarsely ornamented mantle with rounded to square areolae, and a narrow ringleist.

Ecology and distribution: This taxon has a worldwide distribution (Guiry & Guiry 2014) and occurs in a wide range of trophic conditions, but is mostly associated with eutrophic waters (Taylor et al. 2007, Zalat & Vildary 2007, Kiss et al. 2012). It is also associated with water column mixing (Zalat & Vildary 2007), high flood conditions and erosion events, regardless of trophic state (Costa-Böddeker

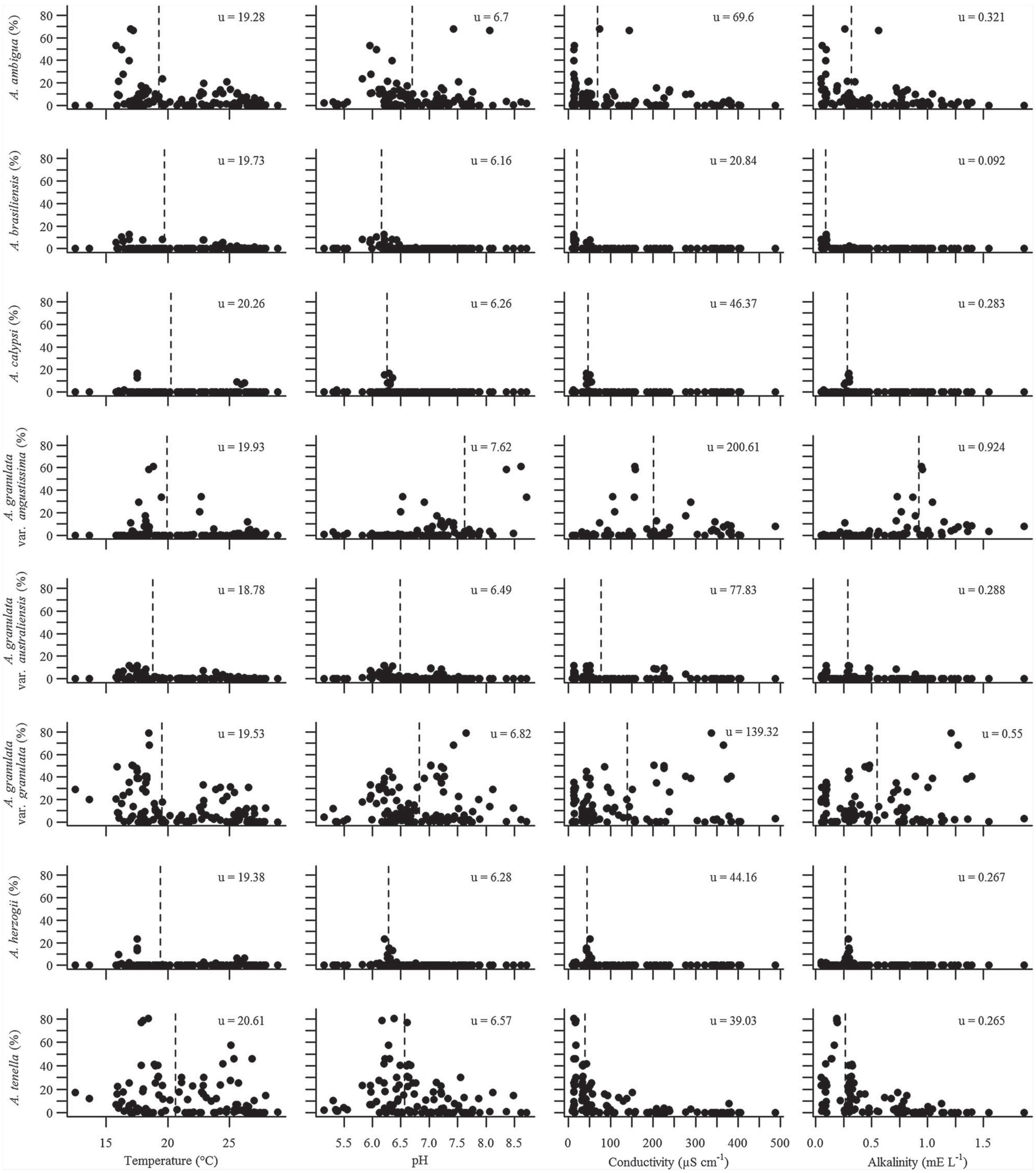


Fig. 2. Relative abundances of eight *Aulacoseira* species in relation to water temperature, pH, conductivity and alkalinity. Dashed lines indicate weighted average optima.

et al. 2012). In addition, an ecotoxicological study demonstrated its tolerance to copper sulphate (Viana & Rocha 2005), an algicide used to control growths of cyanobacterial blooms in some Brazilian reservoirs. In our material, this variety was the most widespread, present in 93% of all samples and in high abundances particularly during winter (Table 2), when water mixing is more frequent. It co-occurred with *A. granulata* var. *angustissima* and presented the second highest TP and TN optima (Fig. 3), confirming its preference for enriched waters.

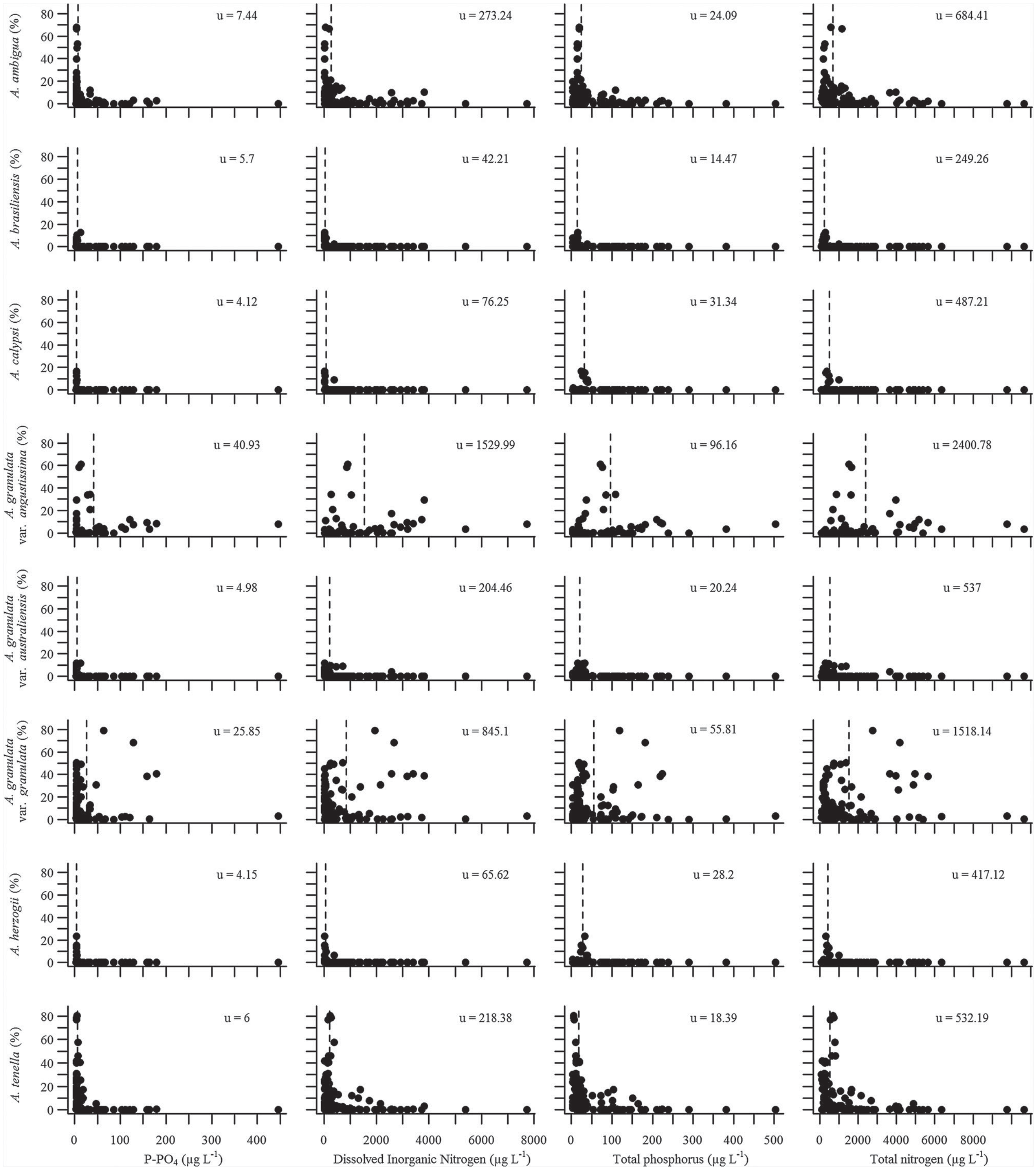
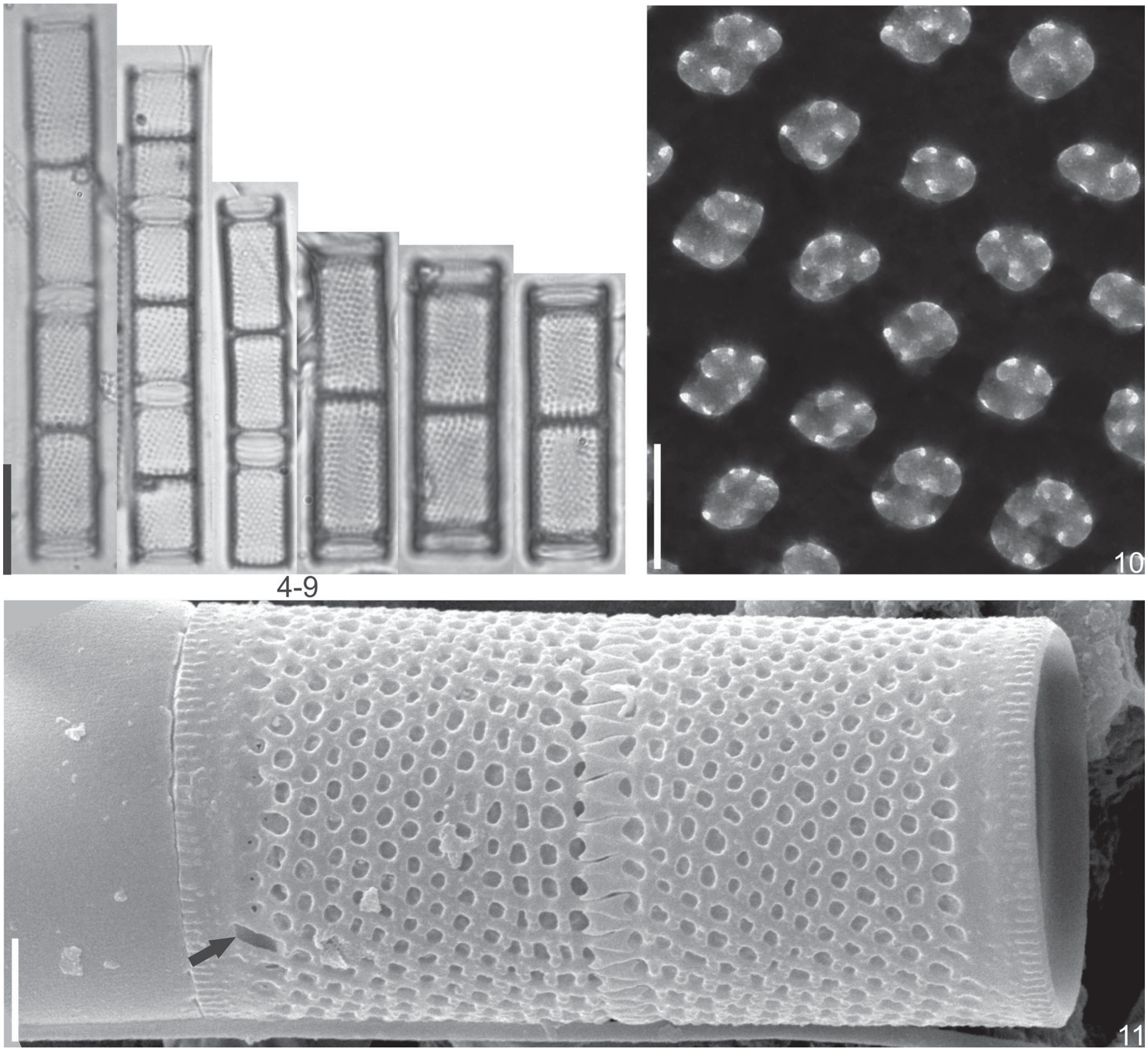


Fig. 3. Relative abundances of eight *Aulacoseira* species in relation to soluble reactive phosphorus (P–PO_4), DIN, TP and TN concentrations. Dashed lines indicate weighted average optima.

***Aulacoseira granulata* var. *angustissima* (O. Müller) Simonsen (Figs 38–40)**

Morphology: This variety differs from the nominate by the presence of a single and elongated separation spine and a narrower valve diameter (3–5 µm) (Hustedt 1930, Krammer & Lange-Bertalot 1991). The nominate variety has commonly two long separation spines and a valve diameter of 5–35 µm (Krammer & Lange-Bertalot 1991).

Ecology and distribution: This is a cosmopolitan taxon (Guiry & Guiry 2014), which is found mainly in eutrophic rivers and lakes (Krammer & Lange-Bertalot 1991, Taylor



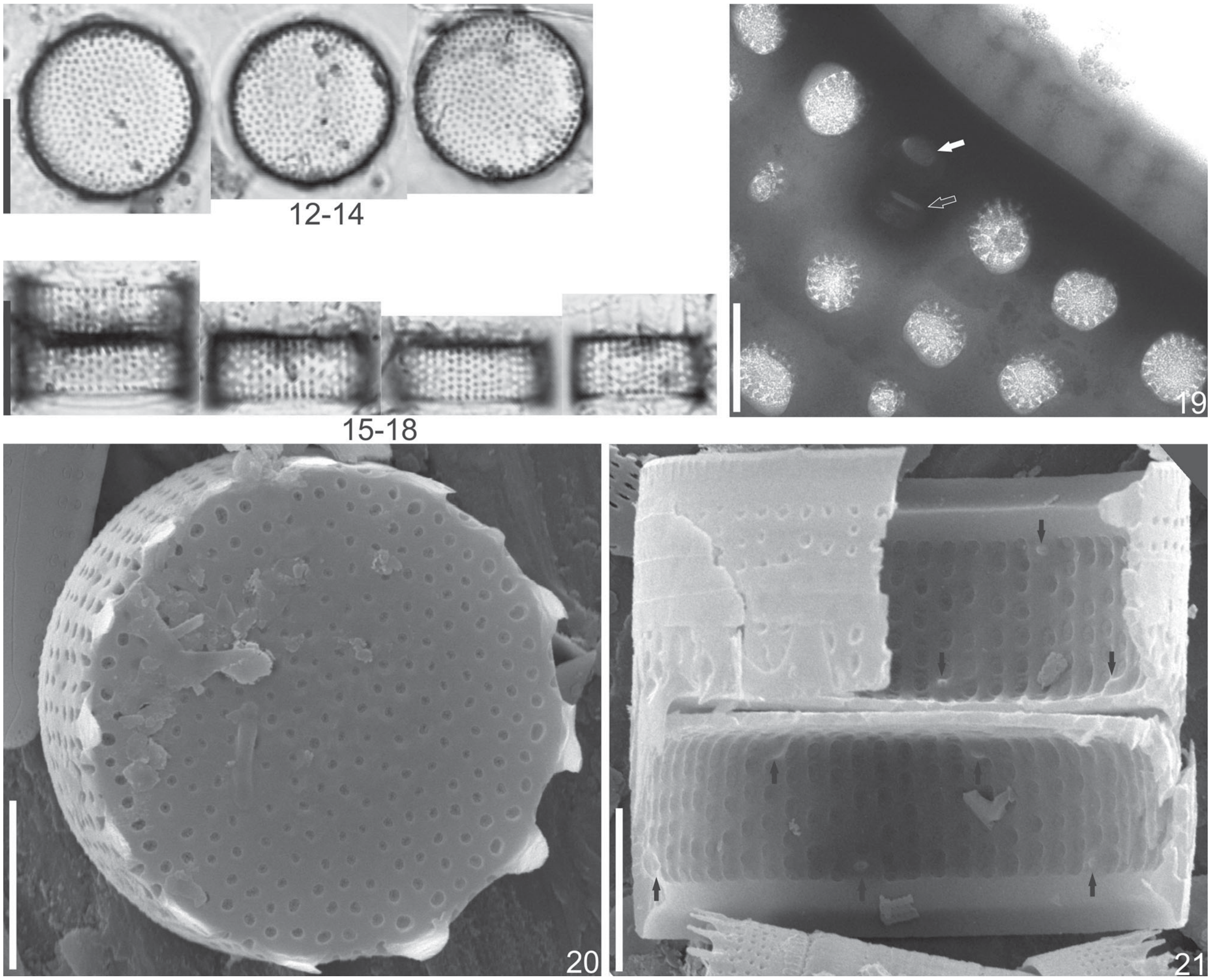
Figs 4–11. *Aulacoseira ambigua*. **Figs 4–9**. Frustules in girdle view, LM. **Fig. 10**. Areolae occlusions, TEM. **Fig. 11**. Linking valves in girdle view, the arrow shows an external opening of rimoportula, SEM. Scale bars = 10 µm (Figs 4–9), 500 nm (Fig. 10), 2 µm (Fig. 11).

et al. 2007). In our data set, this variety was recorded in approximately half of all sites, achieving high abundances in eutrophic reservoirs (Table 2). Compared to other taxa it has the highest ecological optimum for all measured environmental variables, particularly for phosphorus and nitrogen (Figs 2–3).

Aulacoseira granulata var. *australiensis* (Grunow) Moro (Figs 41–42)

Morphology: The variety *australiensis* is characterized by the presence of 1–4 separation spines and conspicuous rimoportulae, visible in LM (Frenguelli 1923, Moro 1991). On the other hand, the nominate variety has one or two long separation spines and the rimoportulae are not visible in LM.

Ecology and distribution: This taxon has been recorded in different parts of the world including South America (e.g., Van Heurck 1880–1885, Tempère & Peragallo 1907–1915, Frenguelli 1923, Moro 1991). No ecological information was found in the literature. In our study, this taxon was found in low abundances in 41% of all sites (Table 2). It was mostly found in reservoirs with low nutrient content in the oligo-mesotrophic range (Fig. 3), low conductivity, slightly acidic waters and at relatively low temperature (Fig. 2). Our data indicate distinct ecological preferences for *A. granulata* var. *australiensis* compared to the nominate variety and *A. granulata* var. *angustissima*.



Figs 12–21. *Aulacoseira brasiliensis*. **Figs 12–14**. Valve face, LM. **Figs 15–18**. Valves in girdle view, LM. **Fig. 19**. Areolae occlusion, external and internal openings of a rimoportula (white and black arrow, respectively), TEM. **Fig. 20**. External view of valve face, SEM. **Fig. 21**. Internal openings of rimoportulae on the mantle (arrows). Scale bars 10 µm (12–18), 0.5 µm (19), 5 µm (20, 21).

***Aulacoseira herzogii* (Lemmermann) Simonsen (Figs 43–48)**

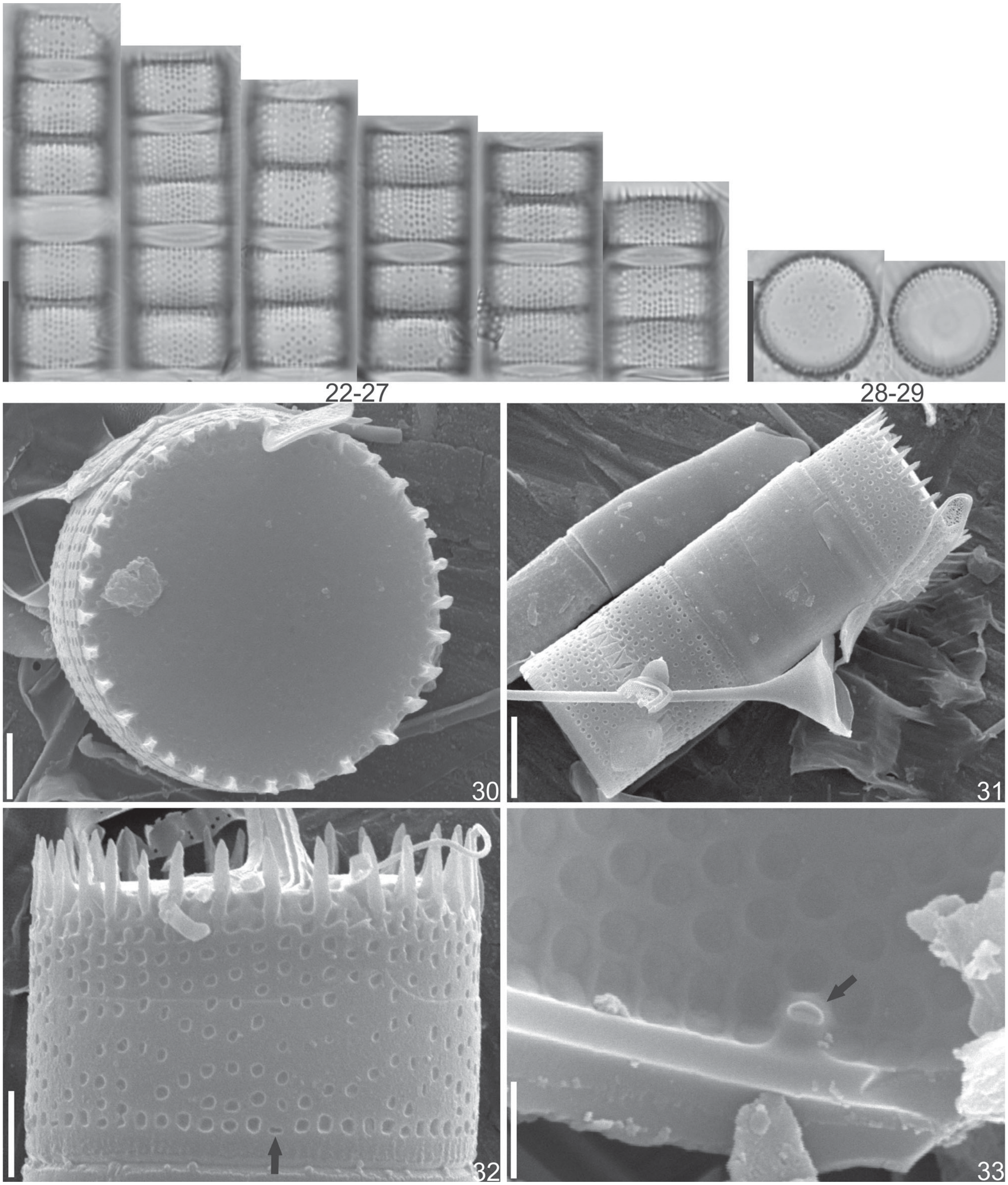
Morphology: In LM, this taxon is easily distinguishable by two to four long spines on opposite sides of the valves and very small mantle areolae. *Aulacoseira herzogii* occurs as single cells or in short chains.

Ecology and distribution: According to Hustedt (1952), *A. herzogii* occurs in tropical and subtropical regions of South America. Further studies report a worldwide distribution (Hickel & Håkansson 1991, Jewson et al. 1993, Guiry & Guiry 2014), including different regions of Brazil (Hickel & Håkansson 1991, Torgan et al. 1999, Tremarin et al. 2009, Silva et al. 2011, Cavalcante et al. 2013). It was found developing in littoral zones in mesotrophic to eutrophic lakes (Houk & Klee 2007). In our materials, it was found in 15.8% of all sites, and usually in low abundances (Table 2); occurring in oligo to hypereutrophic, but mostly in mesotrophic reservoirs (Fig. 3). As mentioned above, this species has similar ecological preferences to, (Figs 2–3) and co-occurred with, *A. calypsi*.

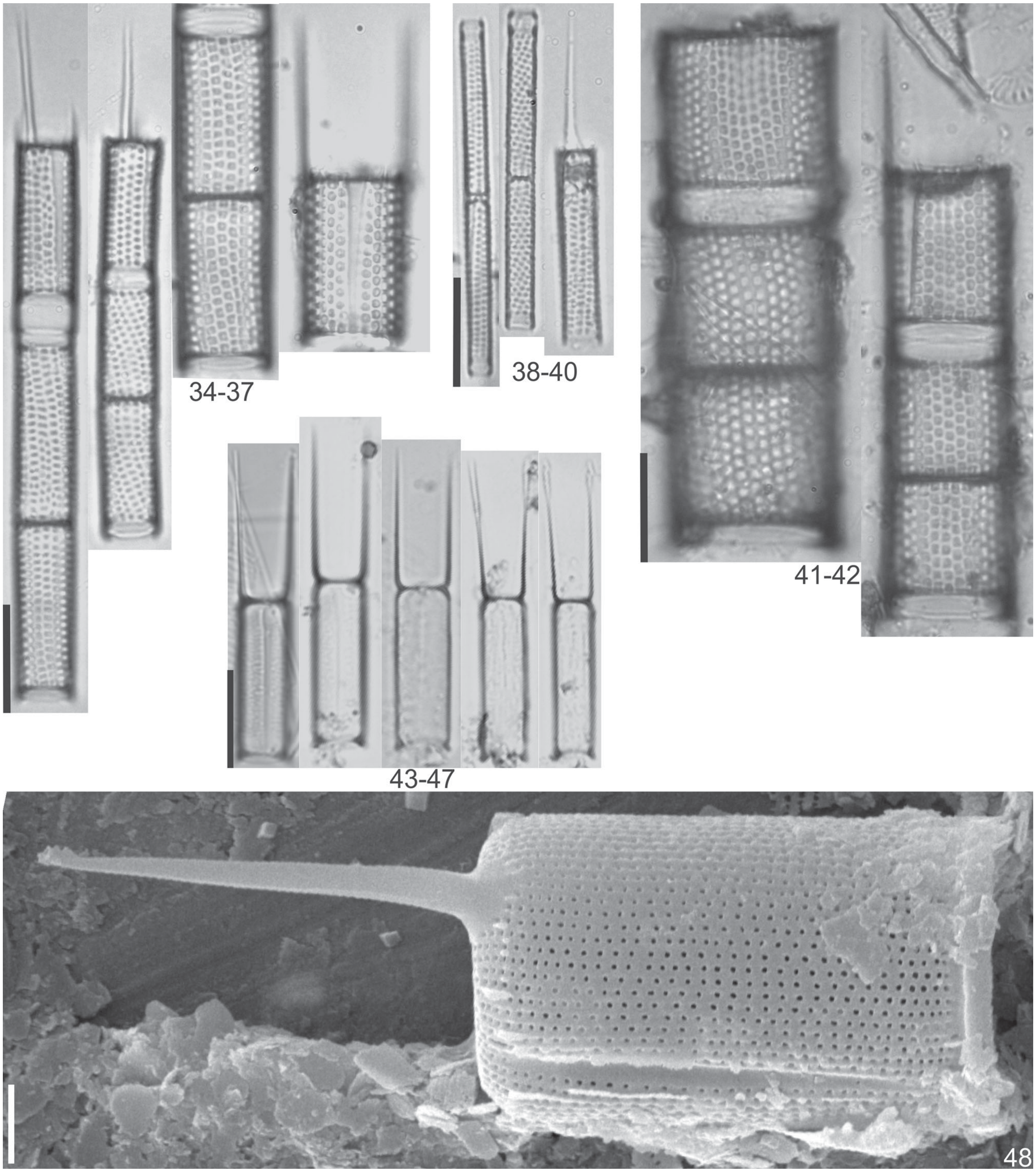
***Aulacoseira laevissima* (Grunow) Krammer (Figs 49–62)**

Morphology: Under LM, this species is distinguishable by its delicate areolae arranged in straight rows on the mantle, valve face completely covered by areolae, and several small linking spines, which in SEM have the shape of an anchor (Krammer & Lange-Bertalot 1991, Krammer 1991b).

Ecology and distribution: *Aulacoseira laevissima* has been reported from different parts of the world (Krammer 1991b, Houk & Klee 2007, Guiry & Guiry 2014), including Brazil, but only in the state of São Paulo (Morandi



Figs 22–33. *Aulacoseira calypsi*. **Figs 22–27**. Frustules in girdle view, LM. **Figs 28–29**. Separation (Fig. 28) and linking (Fig. 29) valves in valve view, LM. **Fig. 30**. External view of separation valve, SEM. **Fig. 31**. Frustule with separation and linking valves in girdle view, SEM. **Fig. 32**. Valve in girdle view showing separation spines, areolae on the mantle and external opening of a rimoportula (arrow), SEM. **Fig. 33**. Internal opening of a rimoportula (arrow), SEM. Scale bars 10 µm (22–29), 2 µm (30, 32), 5 µm (31), 1 µm (33).

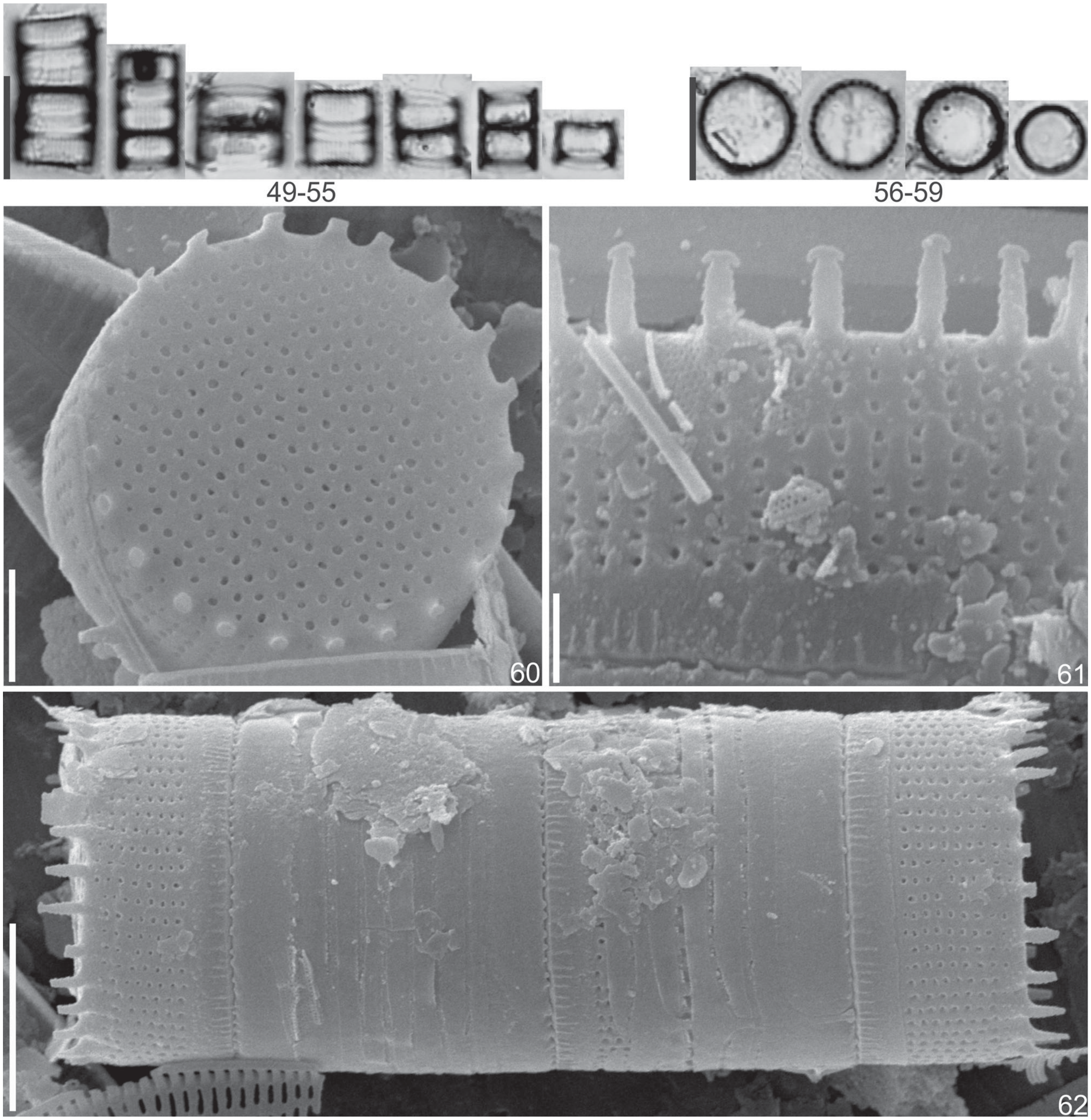


Figs 34–48. *Aulacoseira* species. **Figs 34–37**. *Aulacoseira granulata* var. *granulata*, LM; **Figs 38–40**. *Aulacoseira granulata* var. *angustissima*, LM. **Figs 41–42**. *Aulacoseira granulata* var. *australiensis*, LM. **Figs 43–48**. *Aulacoseira herzogii*. Valves in girdle view, LM (Figs 43–47). Valve in girdle view with a separation spine, SEM (Fig. 48). Scale bars 10 µm (34–47), 2 µm (48).

et al. 2006). This is a rare species with little ecological information (Houk & Klee 2007). In our study, it was found with relative abundances lower than 0.5% in two oligo-mesotrophic reservoirs.

Aulacoseira pusilla **(Meister) Tuji et A. Houki (Figs 63–74)**

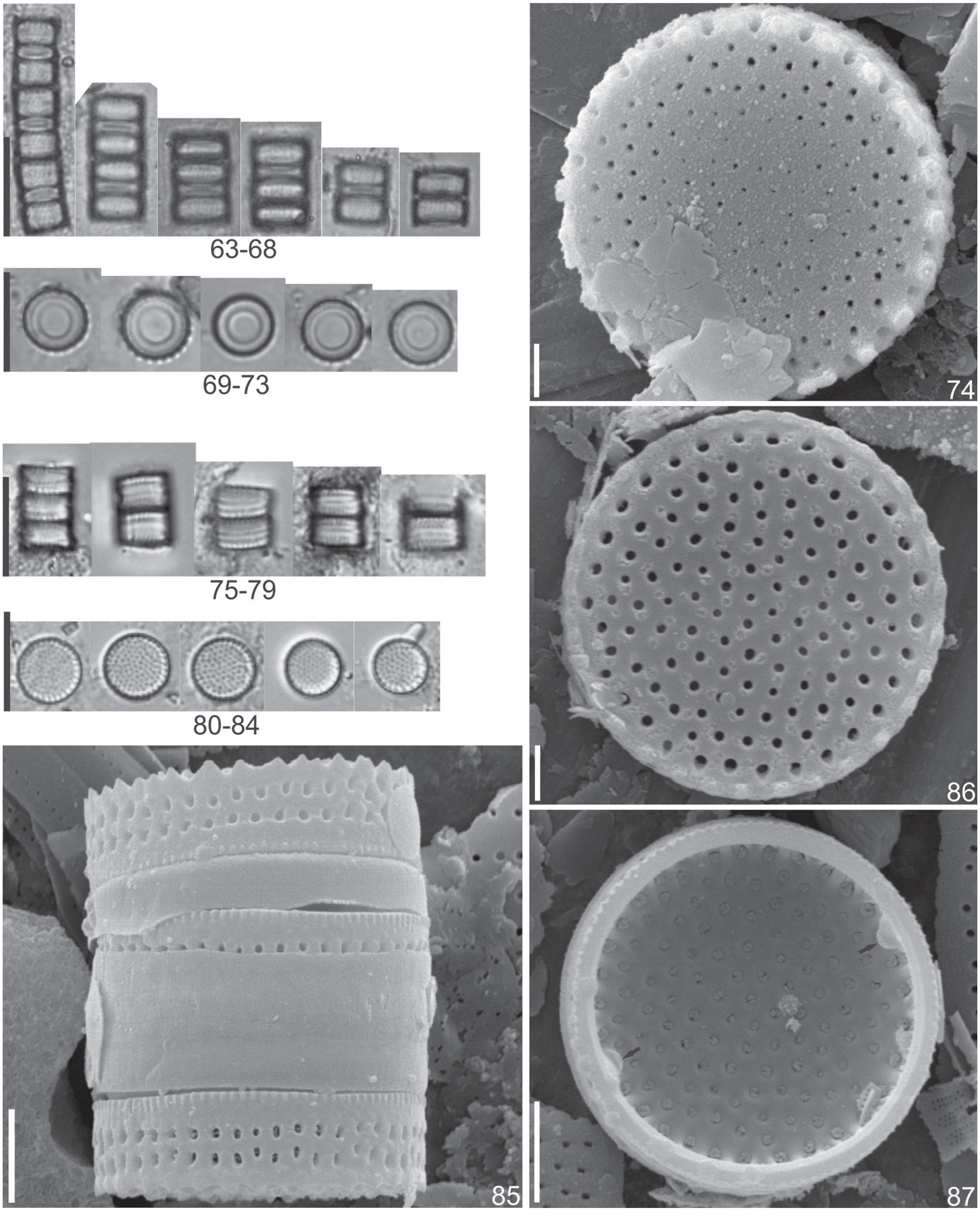
Morphology: This diatom has a similar mantle striation pattern and frustule dimensions to *Aulacoseira alpigena*



Figs 49–62. *Aulacoseira laevissima*. Frustules in girdle view, LM (Figs 49–55). Valve views, LM (Figs 56–59). External view of a valve, SEM (Fig. 60). Detail of a valve showing spines mantle areolae, SEM (Fig. 61). Chain of two frustules in girdle view, SEM (Fig. 62). Scale bars 10 µm (49–59), 2 µm (60), 1 µm (61), 5 µm (62).

(Grunow) Krammer, but its valve face is covered by areolae, and it differs in the number of striae and areolae in the mantle, spine shape, rimoportula morphology and ringleist thickness (Krammer 1991a, Krammer & Lange-Bertalot 1991, Tuji 2002). *Aulacoseira pusilla* differs from other species with shallow mantles by having curved (dextrorse) mantle striae, delicate areolae and a wide ringleist (Potapova 2010).

Ecology and distribution: *Aulacoseira pusilla* has been found in eutrophic environments (Houk & Klee 2007, Taylor et al. 2007, Tuji & Williams 2007). In Brazil, it has commonly been confused with *A. alpigena* (ex. Ludwig & Valente-Moreira 1990, Bicudo et al. 1993, 1995, Ludwig & Flôres 1995, Brassac et al. 1999, Ludwig et al. 2005, Dunck et al. 2012), *Aulacoseira distans* (Ehrenberg) Simonsen (ex. Ludwig et al. 2004, Raupp et al. 2006) or



Figs 63–87. *Aulacoseira* species. **Figs 63–74**. *A. pusilla*. Frustules in girdle view, LM (Figs 63–68). Valve views focused on ringleists, LM (Figs 69–73). External view of a valve face, SEM (Fig. 74). **Figs 75–87**. *Aulacoseira tenella*. Frustules in girdle view, LM (Figs 75–79). Valve views, LM (Figs 80–84). Frustule in girdle view, SEM (Fig 85). External view of a valve face, SEM (Fig 86). Internal view of valve showing rimoportulae (arrows), SEM (Fig 87). Scale bars 10 µm (63–73, 75–84), 2 µm (85, 87), 1 µm (86).

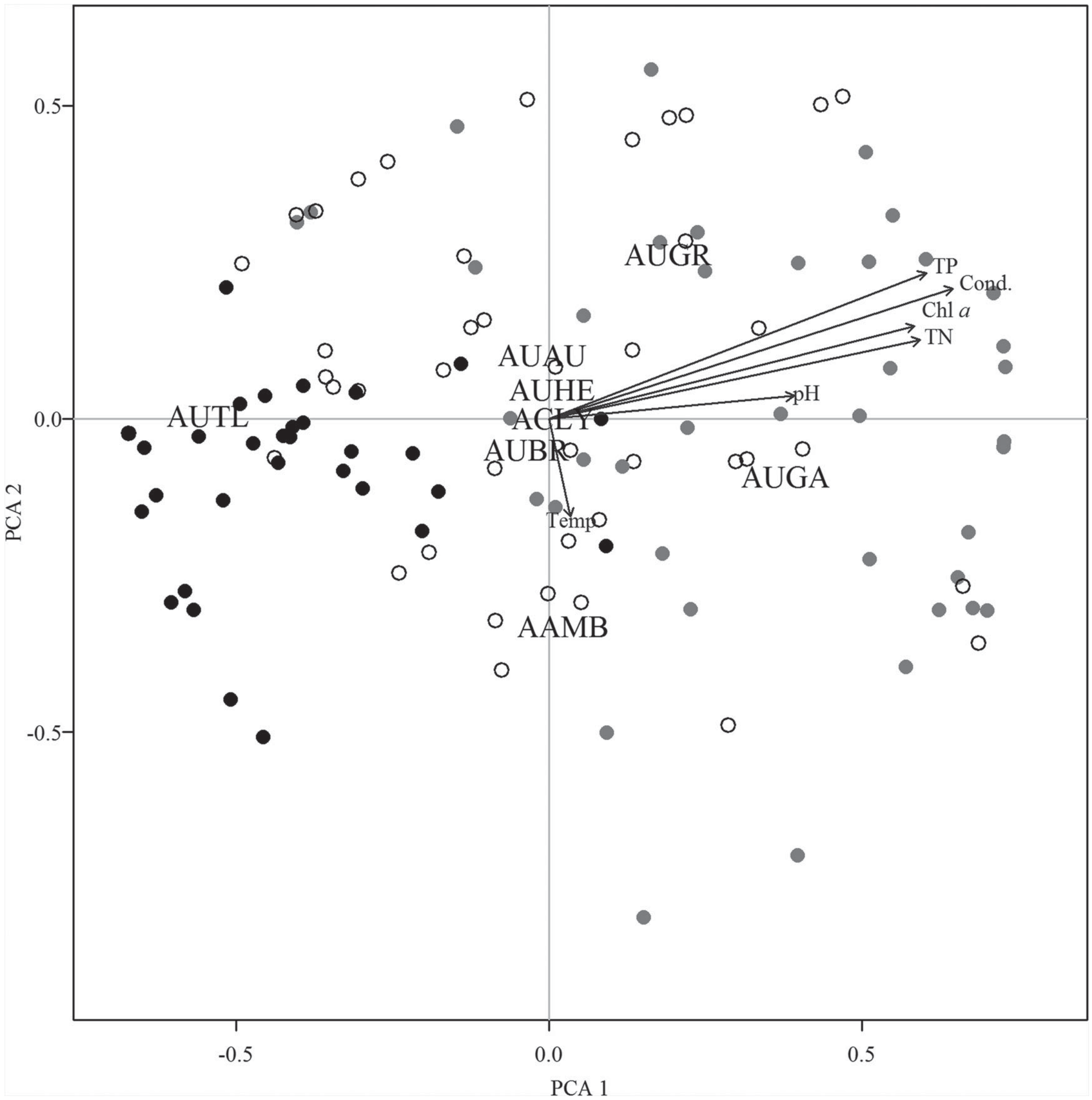


Fig. 88. PCA biplot showing position of samples and species in the ordination space of the first and second PCA axes and a posteriori projection of environmental variables. Black circles are oligotrophic sites, open circles are mesotrophic and grey circles are eu-hypereutrophic sites. Species codes: *A. ambigua* (AAMB), *A. brasiliensis* (AUBR), *A. calypsi* (ACLY), *A. granulata* var. *angustissima* (AUGA), *A. granulata* var. *australiensis* (AUAU), *A. granulata var. granulata* (AUGR), *A. herzogii* (AUHE), *A. tenella* (AUTL). Environmental variables codes: Chlorophyll *a* (Chl *a*), conductivity (cond), total nitrogen (TN), total phosphorus (TP), water temperature (Temp).

A. muzzanensis (ex. Morandi et al. 2006). In our data set, *A. pusilla* was very rare and found at low abundances in two reservoirs of contrasting trophic status, namely oligotrophic and eutrophic, expanding its distribution to clean waters.

Aulacoseira tenella (Nygaard) Simonsen (Figs 75–87)

Morphology: This species is characterized by having its valve face completely covered by areolae, small marginal spines, striae composed of few areolae, shallow mantle and very shallow ringleist (Florin 1981).

Ecology and distribution: The species has been reported from different parts of Europe and USA (Eloranta 1986, Camburn & Kingston 1986, Siver & Kling 1997, Potapova et al. 2008). In Brazil, *A. tenella* was mistakenly recorded as *A. distans* by Tavares & Valente-Moreira (2000), and as *A. alpigena* by Landucci & Ludwig (2005). Subsequent records as *A. tenella* were made by Raupp et al. (2006), Silva et al. (2010), Laux & Torgan (2011) and Cavalcante et al. (2013). *Aulacoseira tenella* has been reported from oligotrophic to oligo-mesotrophic and slightly acidic to neutral waters (Siver & Kling 1997). In this study, it was the second most frequent and abundant species (Table 2), usually present in abundances above 40% in oligotrophic sites. It was well represented in both winter and summer. Compared to other taxa, it has the lowest ecological optimum for TP, conductivity and prefers temperatures around 21°C (Figs 2–3). Although our records expand its distribution in a wide range of nutrient status waters, *A. tenella* was typically associated with oligotrophic and oligo-mesotrophic reservoirs, corroborating the limited ecological information for it.

Principal components analysis

The first PCA axis extracted 45% of the variation, and the analysis indicates the trophic status gradient as the main driver of species distribution. Conductivity had the strongest correlation with the ordination axes, followed by TP (Fig. 88). Oligotrophic sites were placed on the left side of the diagram, and eu- and hypereutrophic sites were mainly on the right side. *Aulacoseira tenella* was the only species associated with clean waters, while *A. granulata* var. *granulata* and *A. granulata* var. *angustissima* were associated with enriched sites, which is in agreement with their ecological optima, particularly for phosphorus and nitrogen (Fig. 3). Other species were associated with mesotrophic and meso-eutrophic sites (*A. ambigua*, *A. brasiliensis*, *A. calypsi*, *A. granulata* var. *australiensis* and *A. herzogii*). Our results highlight three potential indicator taxa, reinforcing the scarce ecological information for *A. tenella* (Siver & Kling 1997), and corroborating previous findings for the varieties of *A. granulata* (Taylor et al. 2007, Zalat & Vildary 2007, Kiss et al. 2012).

In conclusion, our findings report ten *Aulacoseira* taxa from tropical reservoirs in southeastern Brazil, and provide new information on their ecological preferences, adding species optima for several water quality variables. Furthermore, our results expand the ecological information for five species (*A. brasiliensis*, *A. calypsi*, *A. herzogii*, *A. laevissima* and *A. pusilla*) and provide new information for *A. granulata* var. *australiensis*. This study reinforces the need to identify taxa to species level during water quality assessments (Ponader & Potapova 2007), given that different *Aulacoseira* species showed different ecological preferences. Finally, we highlight the need for further regional studies combining floristic and ecological approaches. Such information would improve the accuracy of diatoms as indicators, enhancing their value in water quality assessments and paleoenvironmental reconstructions.

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