**Acanthoceras** and *Urosolenia* species (Diatomeae) in subtropical reservoirs from South Brazil: Ultrastructure, distribution and autoecology

Priscila Izabel Tremarin$^{1,2}$, Eduardo Gomes Freire$^1$, Vanessa Majewski Algarte$^1$ & Thelma Veiga Ludwig$^1$

$^1$Departamento de Botânica, Universidade Federal do Paraná, Curitiba, PR, Brazil. 
$^2$Corresponding author: Priscila Izabel Tremarin, e-mail: ptremin@gmail.com


**Abstract:** *Acanthoceras* Honigmann and *Urosolenia* Round & Crawford *emend.* Rott, Kling & McGregor species were studied based on samples of 19 hydroelectric power plants reservoirs located in the State of Paraná, Southern Brazil. Autoecological informations of *Urosolenia* species complement the study. One *Acanthoceras* and four *Urosolenia* species were identified: *A. zachariasii* (Brun) Simonsen, *U. amazonica* Sala, Núñez-Avellaneda & Vouilloud, *U. eriensis* var. morsa (West & G.S.West) Bukhtiyarova, *U. longiseta* Zacharias and *U. obesa* Freire, Tremarin & Ludwig. Morphological variation of frustules was described and illustrated by optical and scanning electron microscopy, and compared with similar species such as *U. delicatissima* Sala, Núñez-Avellaneda & Vouilloud and *U. eriensis* var. eriensis (H.L.Smith) Round & Crawford. The pioneer record of *U. amazonica* to Brazil and unprecedented details of the ultrastructure of *A. zachariasii* and *U. longiseta* are included in this study. Cellular densities differed among evaluated reservoirs showing strong correlations with inorganic nitrogen concentrations, N/P ratio and temperature. The results suggested higher densities in periods of warmer temperatures and low availability of the nitrogen compounds and confirmed that species respond strongly to local environmental gradients.

**Keywords:** centric diatom, lentic environments, *State of Paraná*, taxonomy.


**Palavras-chave:** ambientes lênticos, diatomáceas cêntrica, *estado do Paraná*, taxonomia.

**Introduction**

*Acanthoceras* Honigmann and *Urosolenia* Round & Crawford *emend.* Rott, Kling & McGregor are centric diatoms worldwide distributed, occurring primarily in plankton of lentic environments (Rott et al. 2006). These genera are mainly characterized by having open girdle bands, cylindrical or sub-cylindrical frustules, conical to semi-conical valves ornamented or not, calyptra and the presence or not of the seta (Round et al. 1990, Rott et al. 2006). The valves of *Acanthoceras* presents two calyptra while *Urosolenia* have only one (Round et al. 1990).

Detailed research on *Acanthoceras* and *Urosolenia* taxa is difficult to realize due to weakly silicified frustules, which are often destroyed by the usual techniques of cleaning and preservation. This fact may be the reason of so scarce records of these genera. Scanning and transmission electron microscopies
have been useful and often essential to distinguish among species, since they enable the visualization of structures indistinguishable in optical microscopy (Morales 2005). Accordingly, identifications of some species performed only with light microscopy should be reviewed (Rott et al. 2006).


According to Reynolds et al. (2002), Urosolenia are included within functional A-group (centric diatoms) characterized by preferring lakes with clear and often well-mixed water, tolerating nutrients deficiency. Representatives of the genus were detected in shallow Amazonian high-waters stages. In Brazilian subtropical reservoirs, Urosolenia species occurred in winter mixed waters (Silva et al. 2005). Ramberg (1987) found A. zachariasii and U. eriensis during stratification of water column, both disappearing in the mixing period. Edlund & Stoermer (1993) remark that Acanthoceras is largely distributed and may be found in alcalin, shallow and eutrophic lakes and rivers from North America. Urosolenia may occur in highly diverse habitats and in oligotrophic to eutrophic conditions.

Thus, this study aimed to describe the morphology and expand the geographic distribution of Acanthoceras and Urosolenia species that occurred in plankton from hydropower plants reservoirs in the State of Paraná, Southern Brazil. Also, we identified the environmental factors closer correlated with Urosolenia species densities.

Material and methods

For the taxonomic analysis, samplings were carried out quarterly at 19 hydroelectric power plants reservoirs from the State of Paraná, Southern Brazil (Figure 1, Table 1), over four consecutive years (2007–2010), at subsurface (< 30 cm depth) and at the limit of the photic zone. A total of 768 phytoplanktonic samples were collected with a van Dorn sampler and were preserved with Lugol’s iodine acetic solution (1%) (Bicudo & Menezes 2006). The material was washed with distilled water to prepare permanent slides mounted with Naphrax® (R.I. = 1.74). The specimens found were measured and photographed under Olympus BX40 light microscopy (LM) equipped with Olympus DP71 image capture, using phase contrast (1000x). Some of the material was dried on aluminum stubs and covered with gold and studied using a JEOL JSM 6360LV scanning electron microscopy (SEM), operated at 15 kV and 8 mm working distance, at the Electron Microscopy Center of the Universidade Federal do Paraná. Analyzed

Figure 1. Sampling locations in the State of Paraná, Brazil. Hydroelectric power plants reservoirs: 01– Capivari, 02– Marumbi, 03– São Jorge, 04– Pitangui, 05– Apucarana, 06– Mourão, 07– Melissa, 08– Rio dos Patos, 09– Chopim, 10– Cavernoso, 11– Segredo, 12– Foz do Areia, 13– Salto do Vau, 14– Jordão, 15– Chaminé, 16– Guaricana, 17– Fundão, 18– Santa Clara, 19– Salto Caxias.

samples (2007–2010) were stored in the Herbarium of the Universidade Federal do Paraná (UPCB). The terminology used in the description of species was based on Round et al. (1990) and Rott et al. (2006).

For the quantitative and ecological analysis, samplings were carried out quarterly over six consecutive years (2007–2012). *Urosolenia* quantification was performed in Uttermöhl chambers (1958) under Olympus IX70 inverted microscope at a magnification of 600 x, enumerated in random fields (Uhelinger 1964) and followed the stabilization curve of the number of species. Sedimentation time of the samples was carried out according to Lund et al. (1958). The physical and chemical analyses (Table 2) were performed by the technical staff of the Instituto de Tecnologia para o Desenvolvimento (LACTEC) following the Standard Methods (APHA 1989).

Environmental data were summarized by a principal component analysis (PCA, Legendre & Legendre 1998) with log transformed and standardized variables. The selection of the axes for the interpretation of the results followed the Broken Stick criteria (Jackson 1993). Spearman rank correlation coefficients were used to measure the degree of association between the densities of *Urosolenia amazonica*, *U. longiseta* and

### Table 1. Data of the sampling sites in the State of Paraná and register number in the herbarium of Universidade Federal do Paraná (UPCB).

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Station</th>
<th>UPCB/Date</th>
<th>Municipality</th>
<th>Geographic coordinates</th>
</tr>
</thead>
</table>

Source: Ribeiro et al. (2006).
<table>
<thead>
<tr>
<th>Sampling Stations</th>
<th>Physical and Chemical Characteristics</th>
<th>Apucaraninha (n=4)</th>
<th>Capivari (n=3)</th>
<th>Chaminé (n=20)</th>
<th>Fundão (n=4)</th>
<th>Guaricana (n=20)</th>
<th>Jordão (n=10)</th>
<th>Mourão (n=9)</th>
<th>Pitangui (n=18)</th>
<th>Rio dos Patos (n=6)</th>
<th>Salto Caxias (n=2)</th>
<th>Santa Clara (n=6)</th>
<th>Segredo (n=14)</th>
<th>São Jorge (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dam depth</td>
<td></td>
<td>9.75</td>
<td>13</td>
<td>13.5</td>
<td>38.5</td>
<td>8.06</td>
<td>58.6</td>
<td>12.11</td>
<td>2.86</td>
<td>3.5</td>
<td>56.5</td>
<td>43.83</td>
<td>46.25</td>
<td>7.6</td>
</tr>
<tr>
<td>Secchi (m)</td>
<td></td>
<td>1.66</td>
<td>2.36</td>
<td>1.84</td>
<td>1.37</td>
<td>1.41</td>
<td>1.52</td>
<td>1.37</td>
<td>0.74</td>
<td>0.41</td>
<td>2.1</td>
<td>1.47</td>
<td>1.44</td>
<td>0.84</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>(mg.L⁻¹)</td>
<td>7.6</td>
<td>5.16</td>
<td>6.9</td>
<td>7.9</td>
<td>8.19</td>
<td>6.68</td>
<td>6.49</td>
<td>7.47</td>
<td>7.21</td>
<td>7.8</td>
<td>7.67</td>
<td>6.58</td>
<td>7.24</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>7.32</td>
<td>7.4</td>
<td>7.66</td>
<td>7.25</td>
<td>7.52</td>
<td>6.89</td>
<td>7.37</td>
<td>7.52</td>
<td>7.13</td>
<td>7.35</td>
<td>7.25</td>
<td>7.17</td>
<td>7.89</td>
</tr>
<tr>
<td>Conductivity</td>
<td>(µS.cm⁻¹)</td>
<td>31.75</td>
<td>70.33</td>
<td>43.12</td>
<td>28.75</td>
<td>25.75</td>
<td>26.7</td>
<td>26.88</td>
<td>48.05</td>
<td>51.5</td>
<td>44.5</td>
<td>31.16</td>
<td>49.14</td>
<td>51.5</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>(mg.L⁻¹)</td>
<td>0.015</td>
<td>0.013</td>
<td>0.017</td>
<td>0.02</td>
<td>0.024</td>
<td>0.015</td>
<td>0.015</td>
<td>0.043</td>
<td>0.061</td>
<td>0.015</td>
<td>0.018</td>
<td>0.024</td>
<td>0.034</td>
</tr>
<tr>
<td>N-NO₃ (mg.L⁻¹)</td>
<td></td>
<td>0.097</td>
<td>0.263</td>
<td>0.091</td>
<td>0.37</td>
<td>0.088</td>
<td>0.414</td>
<td>0.186</td>
<td>0.157</td>
<td>0.575</td>
<td>0.67</td>
<td>0.355</td>
<td>0.745</td>
<td>0.097</td>
</tr>
<tr>
<td>Total inorganic</td>
<td>nitrogen (mg.L⁻¹)</td>
<td>0.2</td>
<td>0.393</td>
<td>0.21</td>
<td>0.482</td>
<td>0.189</td>
<td>0.525</td>
<td>0.295</td>
<td>0.31</td>
<td>0.763</td>
<td>0.78</td>
<td>0.468</td>
<td>0.858</td>
<td>0.192</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>(mg.L⁻¹)</td>
<td>0.762</td>
<td>1.45</td>
<td>0.875</td>
<td>0.662</td>
<td>0.82</td>
<td>0.99</td>
<td>0.916</td>
<td>0.816</td>
<td>1.52</td>
<td>2.3</td>
<td>0.825</td>
<td>1.182</td>
<td>0.73</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td></td>
<td>6.25</td>
<td>3</td>
<td>3.25</td>
<td>6.75</td>
<td>4.4</td>
<td>5.9</td>
<td>9.44</td>
<td>9.61</td>
<td>26.16</td>
<td>6.5</td>
<td>5.5</td>
<td>7.57</td>
<td>10.65</td>
</tr>
<tr>
<td>N/P Ratio</td>
<td></td>
<td>129.6</td>
<td>231.7</td>
<td>146.9</td>
<td>94.7</td>
<td>98.07</td>
<td>171.8</td>
<td>185.3</td>
<td>46.19</td>
<td>56.8</td>
<td>463.5</td>
<td>128.7</td>
<td>120.5</td>
<td>58</td>
</tr>
<tr>
<td>Water retention</td>
<td>time</td>
<td>14</td>
<td>107</td>
<td>121</td>
<td>4</td>
<td>12</td>
<td>10</td>
<td>53</td>
<td>2</td>
<td>2</td>
<td>31</td>
<td>48</td>
<td>45</td>
<td>43</td>
</tr>
<tr>
<td>Classification</td>
<td></td>
<td>lentic-lotic</td>
<td>lentic</td>
<td>lentic</td>
<td>lotic</td>
<td>lentic-otic</td>
<td>lentic-lotic</td>
<td>lentic</td>
<td>lotic</td>
<td>lentic-otic</td>
<td>lentic</td>
<td>lentic-lotic</td>
<td>lentic-lotic</td>
<td>lentic</td>
</tr>
</tbody>
</table>
**Results and discussion**

Five taxa were identified in the qualitative analysis: *A. zachariasii*, *U. amazonica*, *U. eriensis* var. *morsa*, *U. longiseta* and *U. obesa*. The taxa occurred in 15 of the 19 reservoirs (except for Cavernoso, Chopim, Marumbi and Melissa reservoirs). Specimens of *Acanthoceras* and *Urosolenia* were registered in 12% of analyzed samples, being *Urosolenia amazonica* present in 87% of these samples, followed by *U. obesa* (80%), *U. longiseta* (60%), *U. eriensis* var. *morsa* (16%) and *A. zachariasii* (10%).


Basionym: *Attthea zachariasii* Brun, Forschungsberichte aus der Biologischen Station zu Plön 2: 53, pl. 1, fig. 11, 1894.

Synonyms: *Acanthoceras magdeburgense* Honigmann, Archiv für Hydrobiologie und Planktonkunde 5: 78, pl. 2, fig. b, 1910.


Frustules solitary, subcylindrical, straight, 56.5–73.4 µm total long, 6.1–13.5 µm width (Figures 2–5). Valve face straight with conical apices, ornamented with round to irregular areolae, 50–55 in 10 µm, arranged in rows and extending onto the calyptra base (Figures 6, 7). Valve mantle edge surrounded by a thin hyaline margin (Figure 7). Calyptra straight, positioned in the valve apices, 14.9–17.8 µm long, positioned at right to strongly oblique angle with the pervalvar axis. Tip of spine-like extension with four small teeth (Figures 9–11). Terminal seta not observed. Cingulum with several semicircular open and narrow bands, 9–14 in 10 µm, perforated by round poroids, ca. 7 in 1 µm (Figure 8). Bands of the median region of frustule perforated by a few poroids, scarcely distributed. Coarser rounded pores, varying in size and number, present on the girdle bands (Figure 8). Two to four discoid to plate-like chloroplasts per cell (Figures 2–5).

The genus *Acanthoceras* was proposed by Honigmann (1910) when describing *A. magdeburgense* Honigmann, a later synonym of *Attthea zachariasii* Brun. The name *Acanthoceras* had already been proposed by Kützing (1842) for a red alga genus currently considered a later homonym of *Ceramium* Roth (Edlund & Wynne 1996). Since the name *Acanthoceras* Kützing was not in use and that *Acanthoceras* Honigmann was reported for a diatom, Edlund & Wynne (1996) suggested the conservation of the name *Acanthoceras* that was recommended by the Committee for Algae (see Comper 1999).

Although the ultrastructure of *Acanthoceras zachariasii* has been illustrated and described by Round et al. (1990) and the morphology of its resting spores analyzed by Edlund & Stoemer (1993), some taxonomically important details on the frustule morphology of this species remained unknown. The number of calyptra teeth and density of poroids in the girdle bands are recorded for the first time in this study.

The specimens of *Acanthoceras zachariasii* from Brazilian reservoirs showed smaller individuals than the type material of the species, but they were similar to other studied specimens, with intermediate sizes, as can be seen on Table 3. The Brazilian material has smaller calyptra length and higher number of girdle bands when compared with materials analyzed by Huber-Pestalozzi (1942), Rivera (1974), Shirata & Valente-Moreira (1987) and Ferrario et al. (1992) (Table 3). There are few records of the metric variation of *A. zachariasii*. Rivera (1974) remarked that the number of bands is not a constant feature in *A. zachariasii*, so we believe that the specimens analyzed in our study represent an extreme of the population and would not justify the proposition of a new taxon. Anyway, it is necessary to analyze the type material of *A. zachariasii*, especially in SEM, to study the fine ornamentation of the frustules (ex. calyptra teeth, details of the valve, calyptra and bands), for comparison among different populations. However, we advise on this difficult task, given the frequent and fast disappearing of *Acanthoceras* individuals in the stored samples. The low silicified frustules of *Acanthoceras*, as well as *Urosolenia*, do not resist long time in chemical preserved samples (Tremarin et al. 2013).

Table 3. Morphometric features of *Acanthoceras zachariasii* var. *zachariasii* and *A. zachariasii* var. *curvata*.

<table>
<thead>
<tr>
<th>Reference</th>
<th><em>A. zachariasii</em> var. <em>zachariasii</em></th>
<th><em>A. zachariasii</em> var. <em>curvata</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>Brazil</td>
<td>Germany</td>
</tr>
<tr>
<td></td>
<td>Switzerland</td>
<td>Chile</td>
</tr>
<tr>
<td></td>
<td>Brazil</td>
<td>Brazil</td>
</tr>
<tr>
<td></td>
<td>Argentina</td>
<td>Argentina</td>
</tr>
<tr>
<td></td>
<td>Chile</td>
<td>Chile</td>
</tr>
<tr>
<td></td>
<td>Brazil</td>
<td>Brazil</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>Germany</td>
</tr>
<tr>
<td>Country</td>
<td>Brazil</td>
<td>Germany</td>
</tr>
<tr>
<td></td>
<td>Switzerland</td>
<td>Chile</td>
</tr>
<tr>
<td></td>
<td>Brazil</td>
<td>Brazil</td>
</tr>
<tr>
<td></td>
<td>Argentina</td>
<td>Argentina</td>
</tr>
<tr>
<td></td>
<td>Chile</td>
<td>Chile</td>
</tr>
<tr>
<td></td>
<td>Brazil</td>
<td>Brazil</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total frustule length (μm)</td>
<td>56.5–73.4</td>
<td>...</td>
<td>12–100</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Frustule length (μm)</td>
<td>29.1–39.7</td>
<td>60–100</td>
<td>...</td>
<td>42–86</td>
<td>31–45.6</td>
<td>20–36</td>
<td>43–90</td>
</tr>
<tr>
<td>Frustule width (μm)</td>
<td>6.1–13.5</td>
<td>15–20</td>
<td>15–25</td>
<td>8.5–17</td>
<td>9.7–18.1</td>
<td>11–12</td>
<td>8–11</td>
</tr>
<tr>
<td>Calyptra length (μm)</td>
<td>14.9–17.8</td>
<td>...</td>
<td>40–70</td>
<td>24–32</td>
<td>18.6–30.1</td>
<td>20–25</td>
<td>20–30</td>
</tr>
<tr>
<td>Girdle bands (in 10 μm)</td>
<td>9–14</td>
<td>...</td>
<td>3.4–4</td>
<td>4–6</td>
<td>...</td>
<td>4–4.5</td>
<td>4.5–5</td>
</tr>
<tr>
<td>Porous of the bands (in 1 μm)</td>
<td>7</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Teeth of the calyptra</td>
<td>4</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
The species has only one variety, *Acanthoceras zachariasii* var. *curvata* Rivera, proposed by Rivera (1974) based on the frustule curvature in relation to the pervalvar axis.

*Acanthoceras zachariasii* is a freshwater taxon, worldwide distributed, recorded to Germany, Australia, Switzerland, Sweden, Finland, Russia, United States, Chile, Argentina and Brazil (Brun 1874, Hustedt 1930, Cleve-Euler 1951, Rivera 1974, Shirata & Valente-Moreira 1987, Ferrario et al. 1992, Edlund & Stoermer 1993, Medvedeva et al. 2009).

Occurrence in samples (UPCB) – São Jorge reservoir 68884; Pitangui reservoir 68879.

*Urosolenia amazonica* Sala, Núñez-Avellaneda & Vouilloud, Diatom Research 23(1): 164, pl. 1, figs 1–9, 2008.

Frustules solitary or in pairs, cylindrical, straight, 78–194 μm total long, 7.2–12.8 μm width (Figures 12–19). Valve face conical, 2.4–5.4 length, ornamented with rounded areolae 7–9 in 1 μm, randomly arranged and extending onto the calyptra base (Figures 20–22). Valve mantle edge surrounded by a thin hyaline margin (Figures 21, 22). Calyptra straight and eccentric, 24.8–38.2 μm long, positioned at right to slightly oblique angle with the pervalvar axis. Tip of spine-like extension with 4–6 small teeth (Figures 23–26). Terminal seta not observed. Cingulum with several semi-circular open and narrow bands, 8–11 in 10 μm, perforated by round poroids, ca. 7–10 in 1 μm (Figure 27). Valvocopula wider than the other bands, with poroids irregularly distributed and serrated margin (Figures 20, 22).

Urosolenia amazonica is similar to U. eriensis var. eriensis, mainly by the dimensions and shape of frustules, but differs by higher number of girdle bands and valvocopula with serrate margin (Table 4) (Huber-Pestalozzi 1942, Krammer & Lange-Bertalot 1991, Sala et al. 2008). The absence of more detailed features of U. eriensis var. eriensis, as number of calyptra teeth, calyptra length and density of poroids in the bands, difficult a more precise comparison between the two species.

Urosolenia eriensis var. morsa is very similar to U. amazonica in light microscopy. However, the former may have larger valves and valvocopulae with smooth edge (Huber-Pestalozzi 1942, Krammer & Lange-Bertalot 1991, Torgan & Becker 1998). Furthermore, Urosolenia eriensis var. morsa have three teeth in the calyptra as documented by Torgan & Becker (1998) (Table 4). We believe that some Brazilian exemplars recorded as U. eriensis var. morsa in previous studies may be U. amazonica, due to the similarities between the species in light microscopy.

We found some exemplars of U. amazonica with longer total length of frustule and smaller valve length than that reported by Sala et al. (2008) (Table 4), but the valvocopulae serrate and calyptra teeth were always present in the observed specimens.

Urosolenia amazonica was proposed based on material from the Colombian and Peruvian Amazon (Sala et al. 2008), with no subsequent records. Thus, this is the first citation of the species in Brazil.

Occurrence in samples (UPCB) – Apucaraninha reservoir 59524, 60508, 68842; Guaricana reservoir 59533, 60517, 68875, 68875; São Jorge reservoir 59542, 60517, 68860, 68884; Pitangui reservoir 59537, 60521, 68855, 68879; Fundão reservoir 68864, 68888; Foz do Arela reservoir 60515, 60516, 60517, 68872, 68874; Santa Clara reservoir 68863, 68887; Jordão reservoir 59520, 68852, 68876; Segredo reservoir 59543, 59544, 60527, 60528, 68861, 68862, 68885, 68886; Salto Caxias reservoir 68857, 68858, 68881, 68882; Mourão reservoir 59536, 60520,
Table 4. Morphometric and morphological variation of *Urosolenia amazonica* and related taxa.

<table>
<thead>
<tr>
<th></th>
<th><em>U. amazonica</em></th>
<th><em>U. eriensis var. eriensis</em></th>
<th><em>U. eriensis var. morsa</em></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reference</strong></td>
<td>this study</td>
<td>Sala et al. (2008)</td>
<td>Krammer &amp; Lange-Bertalot (1991)</td>
</tr>
<tr>
<td><strong>Total frustule length (µm)</strong></td>
<td>78–194</td>
<td>76–120</td>
<td>40–150</td>
</tr>
<tr>
<td><strong>Frustule width (µm)</strong></td>
<td>7.2–12.8</td>
<td>6–18</td>
<td>6–15</td>
</tr>
<tr>
<td><strong>Frustule length (µm)</strong></td>
<td>32.8–118.8</td>
<td>...</td>
<td>3–4</td>
</tr>
<tr>
<td><strong>Girdle bands (in 10 µm)</strong></td>
<td>8–11</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td><strong>Porous in the bands (in 1 µm)</strong></td>
<td>7–10</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td><strong>Calyptrea length (µm)</strong></td>
<td>24.8–38.2</td>
<td>27–48</td>
<td>28–38</td>
</tr>
<tr>
<td><strong>Valve length (µm)</strong></td>
<td>2.4–5.4</td>
<td>3–9.5</td>
<td>2–15</td>
</tr>
<tr>
<td><strong>Teeth in the calyptrea</strong></td>
<td>4–6</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td><strong>Valvocopula</strong></td>
<td>serrate</td>
<td>serrate</td>
<td>smooth*</td>
</tr>
</tbody>
</table>

* data measured or observed in the illustrations.

68854; Chaminé reservoir 59527, 59528, 60511, 60512, 68845, 68846, 68869, 68870; Rio dos Patos reservoir 68856, 68880.

**Urosolenia eriensis var. morsa** (West & G. S. West)

Basionym: *Rhizosolenia eriensis var. morsa* W. & G. S. West, Transactions of the Royal Society of Edinburgh 41(3): 509, pl. 6, fig. 23, 1905.

Synonyms: *Rhizosolenia morsa* (W. & G. S. West) W. & G. S. West, Transactions of the Royal Irish Academy 33: 109, pl. 11, fig. 5, 1906.

**Urosolenia eriensis var. morsa** (W. West & G. S. West)


Frustules solitary or in pairs, cylindrical, straight, 73.1–143.4 µm total long, 6.9–20.3 µm width (Figures 28–31). Valve face conical, 3.8–7.6 length, ornamented with rounded areolae 7–10 in 1 µm, randomly arranged and extending onto the calyptrea base (Figures 32–34). Valve mantle edge surrounded by a thin hyaline margin (Figure 33, 34). Calyptrea straight and eccentric, 22.4–35.5 µm long, positioned at right to slightly oblique angle with the pervalvar axis. Tip of calyptrea with 2–3 small teeth and one ligula (Figures 36–38). Terminal seta not observed. Cingulum with several semi-circular open and narrow bands, 7–11(18) in 10 µm, perforated by round poroids, ca. 8–9 in 1 µm (Figure 35). Valvocopula wider than the other bands, with poroids irregularly distributed and smooth margin (Figures 32, 34).

The ultrastructure of *U. eriensis var. morsa* was documented by Torgan & Becker (1998), based on samples from Patos lagoon, Southern Brazil. The illustrations show the similarities with the material from the State of Paraná, except by the number of teeth in the calyptrea apex. We found exemplars with 2 or 3 teeth and one ligula, while Torgan & Becker (1998) recorded only 2 teeth and the ligula.

**Urosolenia eriensis var. morsa** differs from the typical variety of species by higher number of girdle bands (Table 4) (Huber-Pestalozzi 1942, Krammer & Lange-Bertalot 1991, Torgan & Becker 1998). *Urosolenia eriensis var. morsa* was found in countries such as Britain, New Zealand, Russia and Brazil (Medvedeva et al. 2009, Tremarin et al. 2009, Guiry & Guiry 2014).

Few specimens of *U. eriensis var. morsa* were found in Brazilian reservoirs samples, and occur together with *U. amazonica*.

Occurrence in samples (UPCB) – Chaminé reservoir 68845, 68846; Guaricana reservoir 59533; São Jorge reservoir 60526.

_Urosolenia longiseta_ (Zacharias) Edlund & Stoermer, 

Basionym: _Rhizosolenia longiseta_ Zacharias, Forschungsberichte aus der Biologischen Station zu Plön 1: 38; fig. 7, 1893.


Frustules solitary, cylindrical, straight to slightly curved, 216–273 μm total long, 5.8–8.5 μm width (Figures 39–46). Valve face conical, 2.4–5.4 μm length, ornamented with rounded to elongate areolae, 6–8 in 1 μm, arranged in almost linear pattern and extending onto the calyptra base (Figures 47, 48). Valve mantle edge surrounded by a thin hyaline margin (Figure 47). Calyptra straight and central, 64–100 μm long, positioned at right to slightly oblique angle with the pervalvar axis. Tip of calyptra with 3–4 small teeth (Figures 51–55). Terminal seta long (Figure 56). Cingulum with several semi-circular open and large bands, 3–4 in 10 μm, perforated by elongate poroids, ca. 7–8 in 1 μm (Figures 49, 50).

When proposed _Rhizosolenia longiseta_, Zacharias (1893) provided only the length of frustule and calyptra (Table 5). Additional, but limited to light microscopy information on the morphology and metric limits was subsequently reported for this species (ex. Krammer & Lange-Bertalot 1991; Huber-Pestalozzi 1942). The failure to record the frustules details of _U. longiseta_ type material has hampered the comparison of this species with populations from different regions of the world and similar taxa. Attempts to analyze a sample of _Rhizosolenia longiseta_ studied by Zacharias from Schleswig-Holstein, Germany (material number E4347–Hustedt Diatom Collection) failed, because complete frustules were not found. Valves poorly preserved and the lack of integrity of the calyptra did not allow to observe the number and morphology of apical teeth.

Our specimens of _Urosolenia longiseta_ had smaller frustules and shorter calyptra than those described by Zacharias (1893), Huber-Pestalozzi (1942) and Krammer & Lange-Bertalot (1991) (Table 5). The metric variation recorded was more related to that cited by Zacharias (1898) and Cleve-Euler (1951).
The ultrastructure of *Urosolenia longiseta* is still poorly known. Only the morphology of its resting spores was well studied by Edlund & Stoermer (1993). Thus, the number and morphology of the calyptra teeth and the areolation pattern of the valves and girdle bands of *U. longiseta* are recorded for the first time in this study.

The frustules of *U. delicatissima* Sala, Nuñez-Avellaneda & Vouilloud and *U. extensa* Karthick & Kociolek are very similar to *U. longiseta*. However, *U. delicatissima* differs mainly by having a bottom, a large labiate-shaped perforation on the valve (Sala et al. 2008). Furthermore, this species may have longer frustules and a high number of bands (Table 5) (Sala et al. 2008, Li et al. 2009). *Urosolenia extensa* have elongate openings in the valve, greater number of girdle bands, longer valves, higher density of areolae (8–9 in 1 μm) and shorter calyptra than that *U. longiseta* (Table 5) (Karthick & Kociolek 2011).

*Urosolenia longiseta* have a worldwide distribution, recorded in Britain, Ireland, North America, New Zealand, Russia, Germany and Brazil (Krammer & Lange-Bertalot 1991, Medvedeva et al. 2009, Tremarin et al. 2009, Guiry & Guiry 2014).

Occurrence in samples (UPCB) – Guaricana reservoir 59533, 60517, 68851, 68875; São Jorge reservoir 59534, 60526, 68852, 68884; Pitangui reservoir 68855, 68879; Fundão reservoir 68864; Foz do Aреia reservoir 59530, 60514, 60515, 60516, 68872; Segredo reservoir 59543, 60527, 68861, 68862, 68885; Saltó Caxias reservoir 68857; Chaminé reservoir 59527, 60511, 60512, 68845, 68846; Jordão reservoir 59520, 68852; Santa Clara reservoir 68863.


Frustules solitary, subcylindrical, straight to slightly curved, 27.6–55.2 μm total long, 6.8–14.2 μm width (Figures 57–61). Valve face conical ornamented with rounded to irregular areolae, 8–10 in 1 μm, randomly arranged and extending onto the calyptra base (Figure 62). Valve mantle edge surrounded by a thin hyaline margin. Calyptra straight and eccentric, 9.7–15.9 μm long, positioned at right to strongly oblique angle with the pervalvar axis. Calyptra in variable position to the frustules (Figures 57–61). Calyptra ornamented by irregular rib-like structures that extend from base until the median portion of this valve projection (Figure 62). Tip of calyptra with 2 small teeth and a central ligula (Figure 63). Terminal seta not observed. Cingulum with several semi-circular open and narrow bands, 13–16 in 10 μm, perforated by round poroids, ca. 10–11 in 1 μm. Coarser rounded pores, varying in size and number, present on both sides of the cingulum (Figure 62). Resting spore subcylindrical, with convex/concave wall, smooth, 5.4–6.5 μm long and 10.1–13.5 μm width (Figure 57).

*Urosolenia obeesa* is a small and delicate taxa recently proposed to South Brazil. Details of frustule morphology and some ecological data of this species were reported by Tremarin et al. (2013) that proposed this taxon. At present, the species was only found in reservoirs of State of Paraná.

Occurrence in samples (UPCB) – Capivari reservoir 59525, 60509, 68843, 68867; Guaricana reservoir 59533, 60517, 68851, 68875; São Jorge reservoir 59523, 60526, 68860, 68884; Pitangui reservoir 59537, 60521, 68855, 68879; Salto do Vau reservoir 59541, 60525, 68859, 68883; Fundão reservoir 68864, 68888; Foz do Aреia reservoir 59530, 59531, 59532, 60514, 60515, 60516, 68848, 68849, 68850, 68872, 68873, 68874; Santa Clara reservoir 68863, 68887; Jordão reservoir 59520, 60518, 60519, 60522, 60524, 68857, 68858, 68881, 68882; Mourão reservoir 59536, 60520, 68854, 68878.

**Ecology**

The ecological preferences of *Acanthoceras* and *Urosolenia* species are poorly known. *Acanthoceras zachariasii* was reported as occasionally abundant and ephemeral in several alkaline and eutrophic environments in Europe, North and South America (Rivera 1974, Beaver 1981, Edlund & Stoermer 1993). In fact, this species was only found at low densities in two studied eutrophic reservoirs in April/2010, (São Jorge reservoir: 37 cells.mL⁻¹ and Pitangui reservoir: 99 cells.mL⁻¹), co-occurring with *Urosolenia* species. Ramberg (1987), when
study of phytoplankton of Lake Kariba, observed that *A. zachariasii* occurred in low density in the end of the rainy season and disappeared with the mixing of water column. According to Edlund & Stoe rmer (1993), the record of *Urosolenia* species for several environments with different physical and chemical conditions can be a result of the erroneous determination of taxa. Thus, we emphasize the importance of taxonomic studies to better define the differences between species and their geographical distribution, aiding subsequent ecological studies.

The first two axes from Principal Component Analysis (PCA) exceed expectations from the broken-stick distribution, suggesting these axes are significant and explained 52.52% of total variance from environmental variables considering 2007–2012. The first axis (27.66%) showed positive correlations with reservoir depth ($r=0.83$) and to molar N/P ($r=0.83$) and negative correlations with total phosphorous ($r=-0.56$) and pH ($r=-0.51$). Water column turbidity ($r=0.76$) and total inorganic nitrogen ($r=0.68$) had a significantly positive correlation and water transparency was negatively correlated ($r=-0.60$) with the second axis (24.86%).

In general, the Jordão reservoir was characterized by greater depth, and São Jorge Pitangui, Guaricana and Chaminé were more alkaline environments. Rio dos Patos and Segredo reservoirs present higher turbidity and nutrient concentrations, but higher transparency characterizes Jordão and Chaminé reservoirs (Figure 64).

*Urosolenia amazonica* showed occurrence frequency of 78.7%, and despite the density values varied markedly, higher average values were recorded at São Jorge, Pitangui and Chaminé. Spearman rank correlation results revealed positive associations between density and pH, but total inorganic nitrogen, nitrate and reservoir depth were negatively correlated (Table 6). A multiple linear regression model was performed and revealed that total inorganic nitrogen was the main factor influencing *U. amazonica* cellular densities. Along with conductivity, water temperature and molar N/P ratio the model explained 12% of variance. According to this model, the conductivity was positively associated with *U. amazonica* density, and negatively correlated to total inorganic nitrogen, water temperature and the molar N/P ratio (Table 7).
## Table 5. Metric and morphological variation of *Urosolenia longiseta* and related species.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Reference</th>
<th>Total frustule length (μm)</th>
<th>Frustule width (μm)</th>
<th>Frustule length (μm)</th>
<th>Girdle bands (in 10 μm)</th>
<th>Pores in the bands (in 1 μm)</th>
<th>Calyptra length (μm)</th>
<th>Valve length (μm)</th>
<th>Teeth in the calyptra</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>U. longiseta</em></td>
<td>Zacharias (1893)</td>
<td>58-154</td>
<td>160</td>
<td>77-176</td>
<td>3-4</td>
<td>7-8</td>
<td>180-200</td>
<td>64-100</td>
<td>2.4-5.4</td>
</tr>
<tr>
<td><em>U. obesa</em></td>
<td>Zacharias (1893)</td>
<td>216-273</td>
<td>58-8.5</td>
<td>59-103</td>
<td>3-4</td>
<td>7-8</td>
<td>180-200</td>
<td>64-100</td>
<td>2.4-5.4</td>
</tr>
<tr>
<td><em>U. amazonica</em></td>
<td>Zacharias (1893)</td>
<td>216-273</td>
<td>58-8.5</td>
<td>59-103</td>
<td>3-4</td>
<td>7-8</td>
<td>180-200</td>
<td>64-100</td>
<td>2.4-5.4</td>
</tr>
<tr>
<td><em>U. delicateissima</em></td>
<td>Cleve-Euler (1893)</td>
<td>154-280</td>
<td>5-14</td>
<td>2-3-4.5</td>
<td>2-3</td>
<td>6-9</td>
<td>90-170</td>
<td>44-99</td>
<td>2.3-7.5</td>
</tr>
<tr>
<td><em>U. extensa</em></td>
<td>Cleve-Euler (1893)</td>
<td>154-280</td>
<td>5-14</td>
<td>2-3-4.5</td>
<td>2-3</td>
<td>6-9</td>
<td>90-170</td>
<td>44-99</td>
<td>2.3-7.5</td>
</tr>
</tbody>
</table>

The performance model selected inorganic nitrogen as the primary determinant of *U. amazonica* density, with a negative coefficient. *Urosolenia longiseta* showed a negative correlation with temperature and N/P molar ratio, both variables were cited as the main determinants with that species density. N/P molar ratio was selected as the most important variable negatively correlated with *U. obesa*. These results suggest the occurrence of higher densities in periods of warmer tempera-
Figures 57–61. *Urosolenia obesa*, LM. Scale: 10 μm. Figures 62–63. *Urosolenia obesa*, SEM. Fig. 62. External view of frustule showing the ornamentation of the valve and girdle bands. Scale: 2 μm. Fig. 63. Detail of calyptra teeth. Scale: 1 μm.

Figure 64. Reservoirs scores (A) derived from principal component analysis and Pearson correlation (B) between the original variables and ordination scores [COND (conductivity); N INOR (total inorganic nitrogen), NO3 (nitrate), NT (total nitrogen), N/P ratio (N/P molar), DO (dissolved oxygen), PT (total phosphorus), Z (depth reservoir), Secchi (water column transparency); W_temp (water temperature); TURB (turbidity)].
tures and low levels of nitrogenated forms (inorganic nitrogen and N/P molar ratio), corroborating the results reported by Flynn (2001) for the phytoplanktonic diatoms community.

As shown, *Urosolenia* species respond more strongly to local environmental gradients, which are highly influenced by particular local characters (as depth and hydrodynamics of the system). Also, the extent of their ecological amplitude determines the distribution and occurrence pattern of these species in the reservoirs of State of Paraná.

**Acknowledgments**

To Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for postdoctoral grant to P. Tremarin, to Fundação Araucária for postdoctoral grant to V. Algarte, and to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) by the scientific productivity grant for T. Ludwig. To the Instituto de Tecnologia para o Desenvolvimento (LACTEC) and Companhia Paranaense de Energia (COPEL) for providing physical and chemical data and samples for the study; and to the staff of the Electron Microscopy Center of Universidade Federal do Paraná for technical assistance.

**References**


Table 6. Values of Spearman’s correlations between species density and environmental variables of the reservoirs. Values in bold = significant correlations.

<table>
<thead>
<tr>
<th></th>
<th><em>U. amazonica</em></th>
<th><em>U. longiseta</em></th>
<th><em>U. obesa</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>0.224</td>
<td>0.179</td>
<td>0.144</td>
</tr>
<tr>
<td>Log Depth</td>
<td>-0.200</td>
<td>-0.341</td>
<td>-0.260</td>
</tr>
<tr>
<td>Log Conductivity</td>
<td>0.136</td>
<td>-0.123</td>
<td>-0.025</td>
</tr>
<tr>
<td>Log Water temperature</td>
<td>-0.081</td>
<td>-0.292</td>
<td>0.087</td>
</tr>
<tr>
<td>Log N/P ratio</td>
<td>-0.145</td>
<td>-0.300</td>
<td>-0.475</td>
</tr>
<tr>
<td>Log Inorganic nitrogen</td>
<td>-0.266</td>
<td>-0.148</td>
<td>-0.314</td>
</tr>
<tr>
<td>Log Nitrate</td>
<td>-0.234</td>
<td>-0.165</td>
<td>-0.268</td>
</tr>
<tr>
<td>Log Total nitrogen</td>
<td>-0.093</td>
<td>-0.225</td>
<td>-0.500</td>
</tr>
<tr>
<td>Log Turbidity</td>
<td>-0.094</td>
<td>0.019</td>
<td>0.223</td>
</tr>
</tbody>
</table>

Table 7. Results of a multiple regression analysis of species densities against environmental variables.

<table>
<thead>
<tr>
<th>Predictor variables</th>
<th><em>U. amazonica</em></th>
<th><em>U. longiseta</em></th>
<th><em>U. obesa</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>3.077 (96)</td>
<td>8.214 (40)</td>
<td>-0.035 (38)</td>
</tr>
<tr>
<td>Log Nitrogen inorganic</td>
<td>-2.516</td>
<td>-2.977</td>
<td>-0.039</td>
</tr>
<tr>
<td>Log Conductivity</td>
<td>0.892</td>
<td>-0.689</td>
<td>2.485</td>
</tr>
<tr>
<td>Log Water temperature</td>
<td>-1.411</td>
<td>-1.653</td>
<td>0.366</td>
</tr>
<tr>
<td>Log N/P ratio</td>
<td>-0.263</td>
<td>-1.324</td>
<td>-0.018</td>
</tr>
<tr>
<td>Log turbidity</td>
<td>-0.081</td>
<td>-1.142</td>
<td>-3.295</td>
</tr>
<tr>
<td>Log Nitrogen inorganic</td>
<td>-1.326</td>
<td>-0.928</td>
<td>1.889</td>
</tr>
<tr>
<td>Log depth</td>
<td>-0.04</td>
<td>0.04</td>
<td>1.030</td>
</tr>
</tbody>
</table>


BICUDO, C.E.M. & MENEZES, M. 2006. Geˆnero de Algas de a´guas Continetais do Brasil. Chave para identificac¸a˜o e descric¸a˜o. Rima, Sa˜o Paulo. 2 a ediç¸a˜o.


