DIATOMS FROM THE COLOMBIAN AMAZON: SOME SPECIES OF THE GENUS *Eunotia* (BACILLARIOPHYCEAE)

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ABSTRACT - This research was carried out in three of the most important basins of the Colombian Amazon (Upper Solimões, Içа and Japurá Rivers). The creeks and lakes that were studied contain abundant diatom species, particularly those of the genus *Eunotia*. Ten species are described; five of them are registered for the first time in the Amazon basin, and six in all of Colombia. All taxa were photographed with scanning electron microscopy. Fine valve morphology of *E. anamargariate*, *E. pseudoindica*, *E. triodon*, and *E. zydodon* var. *compacta* is described for the first time.

Key-words: Diatoms, *Eunotia*, distribution, ecology, Colombian Amazon Basin.

Diatomáceas da Amazônia Colombiana II: Algumas Espécies do Gênero *Eunotia* (Bacillariophyceae).

RESUMO - O trabalho realizou-se nas três bacias mais importantes da Amazônia Colombiana (Alto Solimões, Içá e Japurá). Os igarapés e lagos estudados apresentam alta riqueza de diatomáceas, principalmente do gênero *Eunotia*. Foram descritas 10 espécies e, pela primeira vez, a morfologia das valvas de *E. anamargaritae*, *E. pseudoindica*, *E. triodon* e *E. zydodon* var. *compacta*, foram descritas ao microscópio eletrônico. Dentre as espécies de *Eunotia*, encontradas no presente estudo, seis são primeiras citações para a Colômbia e cinco para a região amazônica.

Palavras-chave: Diatomáceas, *Eunotia*, distribuição, ecología, Amazônia Colombiana.

Introduction

Diatom species from temperate regions of South America are mostly cosmopolitan or characteristic of those climatic zones of the world. However, South American tropical habitats seem to have a particular flora. This is evident in classic papers (Hustedt, 1965; Schmidt *et al*., 1874-1959) and in recent ones (Reichardt, 1995; Metzeltin & Lange-Bertalot, 1998). Among tropical environments, Amazonia is very interesting due to high biodiversity. Nevertheless, there are just a few taxonomic studies of diatoms from this region (Souza-Mosimann *et al*., 1997 in Brazil; Oliveira & Steinitz-Kannan, 1992 in Ecuador; and Sala *et al.,* 1999, 2002 in Colombia). There are also some references in phytoplankton papers (Uherkovich, 1976; Uherkovich & Schmidt, 1974; Uherkovich & Rai, 1979; Uherkovich & Franken, 1980; Duque, 1998) and in the morphologic and taxonomic work of Metzeltin & Lange-Bertalot (1998).

As a result of a preliminary study carried out in the Colombian Amazon,

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103 diatom taxa were identified. Some of these species could be accurately determined, but 35 could not be associated to any described taxa in the literature, suggesting that there is a rich unknown diatom flora in these habitats. The aquatic waterbodies sampled have conditions of low to moderate trophic level, pH between 4.6 - 7.4, low transparency (0.5-1.67 m of Secchi disc), and high temperature (26-32ºC). In Amazonian aquatic environments conductivity is low, especially in Colombia in some of the study sites like Lake Taraira were registered values of 5 $\mu S\ cm^{-1}$ due to the influence of the Guayana Shield (Furch & Klinge, 1978, 1982; Gibbs, 1970; Duque *et al.*, 1997),

One of the best-represented genera in the study area is *Eunotia* with 27 species, near 30% of the studied taxa. *Eunotia* is a large genus that comprises around 200 species (Van Landingham, 1969). Despite its abundance in freshwater habitats (especially acid waters), there are few studies about species' valve structure. This is evident since in the bibliographic compilation on fine structure of the diatom taxa of Gaul *et al.* (1993) there are references for about 50 species. Round *et al*. (1990) pointed out that a revision at species level is necessary. In addition, there are difficulties of species identification due to the great variability of valve outline and dimensions throughout the life cycle (Mayama, 1992; Mayama & Kobayasi, 1991).

The genus has a world-wide distribution, but numerous species are restricted to tropical areas. A modern and exhaustive revision of the group was done by Krammer & Lange-Bertalot (1991), but these authors based their research principally on materials collected in European temperate environments. The first comprehensive analysis of tropical species using electron microscopy showed the species richness of the genus in South American tropical environments and found that 20% of the analyzed taxa belong to *Eunotia* (Metzeltin & Lange-Bertalot, 1998). On the basis of the studies done with both light and electron microscopy they described nearly 40 new species of the genus. Although they analyzed materials from Amazonia there are no references about the Colombian portion of the basin.

The aim of this paper is to the contribute to knowledge of the diatom flora and the tropical species of *Eunotia* from the Colombian Amazon through an analysis of the fine morphology of some taxa collected in this area.

Materials and Methods

Samples for the analysis were collected during 1993 and 1994 in seven different water bodies in the Colombian Amazon basin: Tarapoto Lake, Arara Creek, Resaca Lake, Tunda Lake, belong to Solimões River (Amazon River), Quinina Lake to Içа River (Putumayo) and Taraira I Lake to Japurá River (Caquetá). General information about the study area is given in Sala *et al.* (2002).

Horizontal and vertical tows were made with a plankton net (mesh

size = 24 μm) at different depths of the photic zone, and benthic diatoms were sampled by squeezing macrophytes. At each sampling site physical and chemical parameters: pH, dissolved oxygen, temperature, water transparency (Secchi disc) and conductivity were registered (Tab. 1).

Samples were fixed with 6-8 % formaline and were treated to eliminate organic matter following the method described in Hasle & Fryxell (1970) and/or in a muffle furnace at 500 °C during 10 minutes. Samples for light microscopy (LM) were mounted in Hyrax and for scanning electron microscopy (SEM) were mounted on glass stubs and then metalized with gold-palladium. Observations were carried out with a Wild M20 LM and a Jeol TM 100 SEM.

Materials are deposited in the Colección Ficoteca Amazónica at the Universidad Nacional de Colombia (Tab. 1). Unclean and cleaned subsamples and permanent slides are deposited at the Herbario of the Departamento Científico Ficología, Museo de Ciencias Naturales de La Plata.

Results

Eunotia anamargaritae (Hustedt) Metzeltin & Lange-Bertalot Figs.1 E-G

Metzeltin & Lange-Bertalot 1998: 51, pl. 37, fig. 9.

Bas.: *Eunotia zygodon* var. *elongata* Hustedt, 1913 in Schmidt *et al.* 1874-1959: Atlas Diat. Kund. Reis. pl. 287, fig. 14.

Valves isopolar with the ventral margin slightly concave and the dorsal one with two undulations; ends not differentiated from the rest of the valve. Striae uniseriate, parallel or slightly radial alongside the valve face and strongly radial at the ends. Areolae small, not visible with LM. Raphe indistinguishable at LM; with SEM it is possible to see that it is well developed on the mantle, oblique at valve face without dilated endings. Girdle bands with several rows of poroids. Dimensions: length: 178-228 μm; breadth: 17-20 μm; striae in 10 μm: 14-17; areolae in 10 μm: 20.

Studied Material: samples 163, 312.

Ecology: in the study area the species was collected in habitats with pH 4.8-6.6, conductivity: 10-106 $\mu S.cm^{-1}$ and transparency: 0.60-0.65 m. The range of variability of environmental parameters is rather wider than that mentioned in Sala *et al.* (2002).

Distribution: Demerara River, Guyana (Krammer & Lange-Bertalot, 1991); Brazilian Amazon (Metzeltin & Lange-Bertalot, 1998) and Colombian Amazon (Sala *et al.* 2002).

Observations: In the literature this species was described only with LM, here we give details of fine valve morphology.

Eunotia camelus Ehrenberg Figs. 1 A-D

Ehrenberg 1841 (1843): 125 (413), 2/1, fig. 1.

Valves slightly curved, dorsal margin with two to four undulations and ventral margin slightly concave; ends of the valve subrostrate, dorsally bent. Striae slightly radial, parallel at

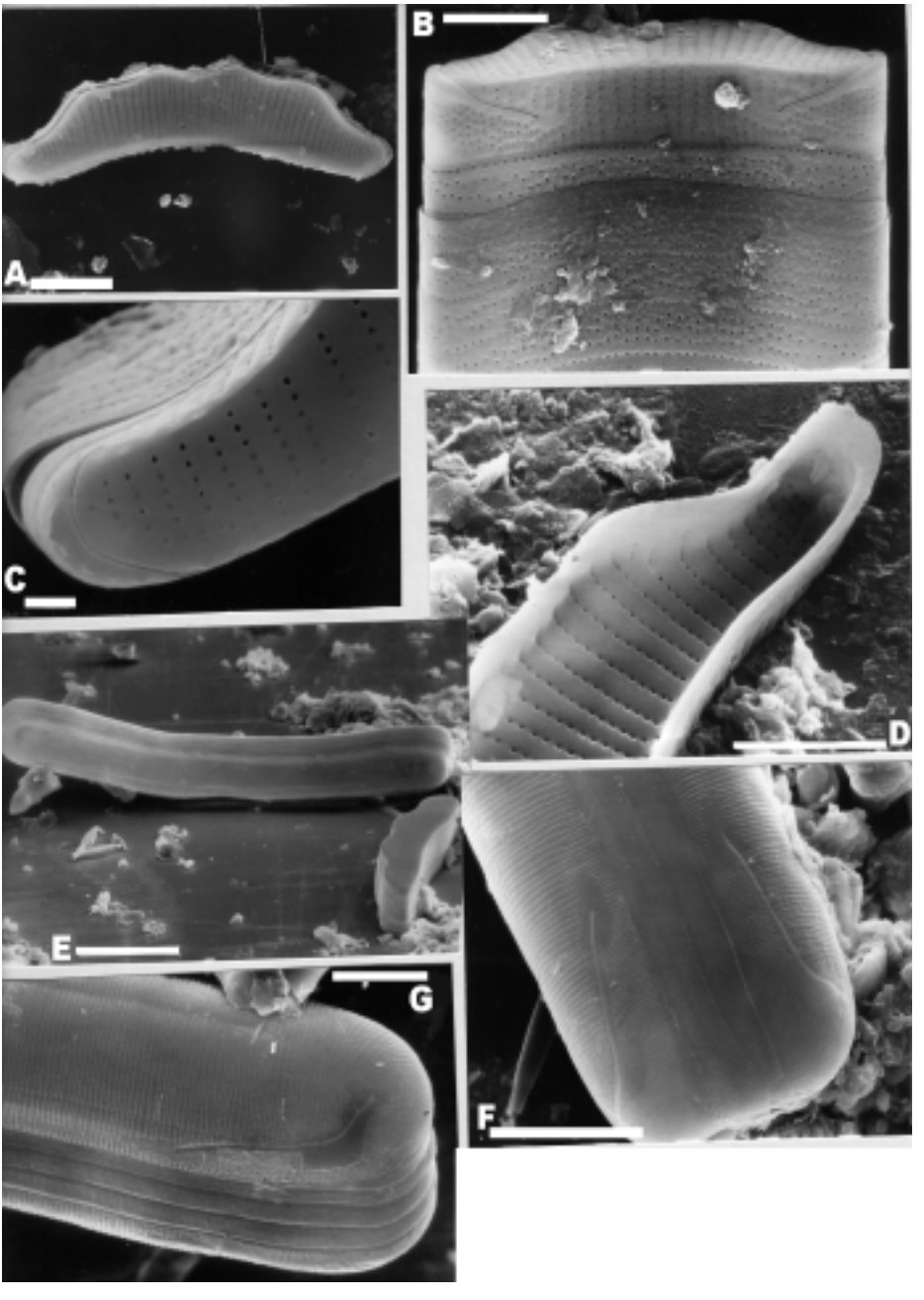

Figure 1. SEM. Scale bars: 1 µm: C; 5 µm: B, D, F; 10 µm: A, E, G.

A-D *Eunotia camelus*. **A:** external valve view. **B:** frustule in girdle view, detail of girdle bands. **C:** external view, detail of raphe and striae. **D:** internal view, detail of rimoportula and helictoglossa. ***E-G*** *Eunotia anamargaritae.* **E:** external valve view. **F:** external view, detail of raphe and girdle bands. **G:** detail of raphe and girdle bands in external view.

Table 1. Physical and chemical characteristics of sampling sites.

Sample	Location	Date	Sampling Type of community	Temperature (C°)	pH	Conductivity (µS cm-1)	Transparency (cm)
159	Tarapoto Lake, Puerto Nariño	09/01/93	Phytoplankton	32	6.0	84	50
163	Arara Creek, Leticia,	02/03/93	Periphyton	27	6.6	106	65
196	Quinina Lake, Tarapacá.	02/03/93	Periphyton	26	5.5	12	112
270	Resaca Lake, Mocagua island	19/08/94	Periphyton	30	7.4	180	150
285	Tunda Lake, Leticia	16/08/94	Phytoplankton	27	6.7	220	40
312	Amauri Creek, La Pedrera	07/11/94	Periphyton	26	4.8	10	60
329	Taraira I Lake, Apaporis River, Vaupés	09/11/94	Periphyton	28	4.8	5	160

the valve center, interstriae broad. Areolae circular indistinguishable at LM. Raphe lying at the valve face, nearly straight, short and oblique at the mantle, raphe endings not dilated. Helictoglossae small and rimoportula simple, elongated in apical sense. Girdle bands incomplete with a few and distant rows of poroids. Dimensions: length: 17.5-52 µm; breadth: 5-8 µm; striae in 10 µm: 9-13 (valve face) and 20 (mantle).

Studied material: samples 159, 163 and 312.

Ecology: In the studied area the specimens were collected in habitats with pH: 4.8-6.6; conductivity: 10-106 µS.cm^{-1} and transparency: 0.50-0.65 m.

Distribution: cosmopolitan. In Amazonia recorded by Oliveira & Steintz-Kannan (1992), Souza-Mosimann *et al*. (1997), Metzeltin & Lange-Bertalot (1998) and Sala *et al.* (2002).

Observations: in Sala *et al.* (2002) this species was analyzed only with LM, here we give details of valve morphology.

Eunotia glacialis Meister
Figs. 2 A-C

Meister 1912: 85, pl. 10, figs. 2-3.

Valves isopolar, slightly arcuate, ends subcapitated, slightly differentiated from the rest of the valve. Striae uniseriate, parallel; areolae circular, indistinguishable at LM. Raphe visible at LM, crossing the valve face and undulate, oblique with dilated ends at the mantle. Girdle bands with several rows of poroids. Dimensions: length: 93-124 µm; breadth: 7-9 µm; striae in

10 µm: 7-12; areolae in 10 µm: 32 (only one specimen measured).

Studied material: samples 159, 270 and 285.

Ecology: present in acid waters, usually cool, with low mineral content (Patrick & Reimer, 1966). Krammer & Lange-Bertalot (1991) mentioned this species in habitats with low to slightly high electrolytic concentrations. In the studied area the specimens were collected in sites with: pH: 6-7.4; conductivity: 84-220 µS.cm^{-1} and transparency: 0.4-1.5 m.

Distribution: Northern Hemisphere (Krammer & Lange-Bertalot, 1991). French Guyana (Reichardt, 1995).

Observations: our specimens have a row of little spines at the end of the valve, this characteristic is neither shown in the materials from European temperate regions studied by Krammer & Lange-Bertalot (1991) nor in those from South America illustrated in Reichardt (1995). In the Brazilian Amazon Souza- Mossimann *et al*. (1997) described some specimens as *E.* cf. *glacialis*, but our materials differ from them in dimensions and striae density.

Eunotia guianense (Ehrenberg) De Toni
Figs. 2 G-H

De Toni 1862: 792.

Bas.: *Himantidium guianense* Ehrenberg, (1841) 1843. Abh. Königl. Akad. Wiss. Berlin: 417, 2/1, fig. 4.

Syn.: *Eunotia pileus* var. *guianense* (Ehrenberg) Reichardt, 1995. Die diat. Ehr. Mat. von Cayenne, Guy. Gall. Germany: 31; pl. 5, figs. 1-8; pl. 24, figs. 9-10.

Valves bilobated, slightly arcuate with subacute ends. Striae uniseriate parallel. Areolae circular, visible with LM. Raphe short, straight in the first half of the valve face and curved on the rest; raphe endings not dilated. Dimensions: length: 42-64 µm; breadth at the center: 10-14 µm; breadth at the end: 14-20 µm; central striae in 10 µm: 9-12; areolae in 10 µm: 20-22.

Studied Material: samples 159 and 163.

Ecology: in the study area the specimens were collected in two sites with pH 6-6.6; conductivity: 84-106 µs.cm^{-1} and transparency: 0.5-0.65 m.

Distribution: Lago Calado, Brazil (Metzeltin & Lange-Bertalot, 1998), Cayenne (Reichardt, 1995) and Colombian Amazon (Sala *et al.,* 2002).

Observations: in the nomenclatural aspects we followed Metzeltin & Lange-Bertalot (1998). This species was illustrated in Sala *et al.* (2002) only with LM (as *E. pileus* var. *guianense*), here we give details of fine valve morphology.

Eunotia naegelii Migula
Figs. 3 A-B

Migula 1907: 203, fig. 140: 1-6.

Valves isopolar, arcuate, ends subcapitated slightly curved to the dorsal side. Striae uniseriate, parallel, slightly radial at the poles, interstriae wide. Areolae circular, not visible with LM. Raphe fissure curved back towards the center of the valve; raphe endings expanded. Rimoportula small. Girdle bands with one row of poroids.

Dimensions: length: 38-152 µm; breadth: 3-5 µm; striae in 10 µm: 16-20; areolae in 10 µm: 47-57.

Studied material: samples 159, 163 and 196.

Ecology: present in acid water with low mineral content (Patrick & Reimer, 1966). In the studied area the specimens were collected in habitats with: pH: 5.5-6.6; conductivity: 12-106 µS. cm^{-1} and transparency: 0.5-1.12 m.

Distribution: cosmopolitan (Krammer & Lange-Bertalot, 1991). This is the first mention of the species in the Amazonian region.

Eunotia* cf. *paludosa Grunow
Figs. 2 D-F

Grunow 1862: 336, pl. 6, fig. 10.

Valve isopolar, slightly arcuate, dorsal and ventral sides parallel. Ends subcapitated. Striae parallel along the valve face, radial at one pole. Areolae circular, not visible with LM. Raphe oblique at the valve face, raphe endings slightly expanded. Helictoglossae conspicuous, rimoportula small, on the mantle at the end of the valve. Girdle bands with several rows of poroids. Dimensions: length: 41-59 µm; breadth: 4-7 µm; striae in 10 µm: 15-20; areolae in 10 µm: 34-45.

Studied material: samples 159, 312 and 329.

Ecology: often found associated to mosses in acid waters of low mineral content, also in bogs and small streams (Patrick & Reimer, 1966). In the study area the specimens were collected in habitats with: pH: 4.8-6, conductivity: 5-84 µS.cm^{-1}, transparency: 0.50-1.6 m.

Distribution: cosmopolitan (Krammer & Lange-Bertalot, 1991).

Observations: Metzeltin & Lange-Bertalot (1998) transferred materials from Demerara River described in Hustedt (1930) as *E. paludosa* Grunow to *E. distinguenda* but our materials differ from the specimens illustrated by Metzeltin & Lange-Bertalot (1998) in dimensions and valve outline and fine valve morphology. In addition, the specimens studied by us are wider and have a less number of striae in 10 µm than those described by other authors, e.g. breadth: 2-3(4) µm and 2-4 µm; striae en 10 µm: (16) 19-25 (32?) and 20-25 in Krammer & Lange-Bertalot (1991) and Patrick & Reimer (1966) respectively.

Eunotia pseudoindica Frenguelli
Figs. 3 C-E

Frenguelli, 1941: 307.

Syn.: *Eunotia indica* Frenguelli 1933. An. Mus. Nac. Hist. Nat., Bs. As.: 453, pl. 9, figs. 11-13.

Valves isopolar, ventral margin straight and dorsal margin convex; endings elongated and attenuated at the poles, well differentiated from the rest of the valve. Raphe visible with LM. Striae uniseriate, parallel alongside the valve and radial at the poles alternating with shorter striae at the dorsal margin. Areolae circular, visible with LM. Rimoportula at the end of the valve in oblique position. Dimensions: length: 50-52 µm; breadth: 9,6-10 µm; striae in 10 µm: 10-11; areolae in 10 µm: 20-28.

Studied material: sample 159.

Ecology: in the literature there is

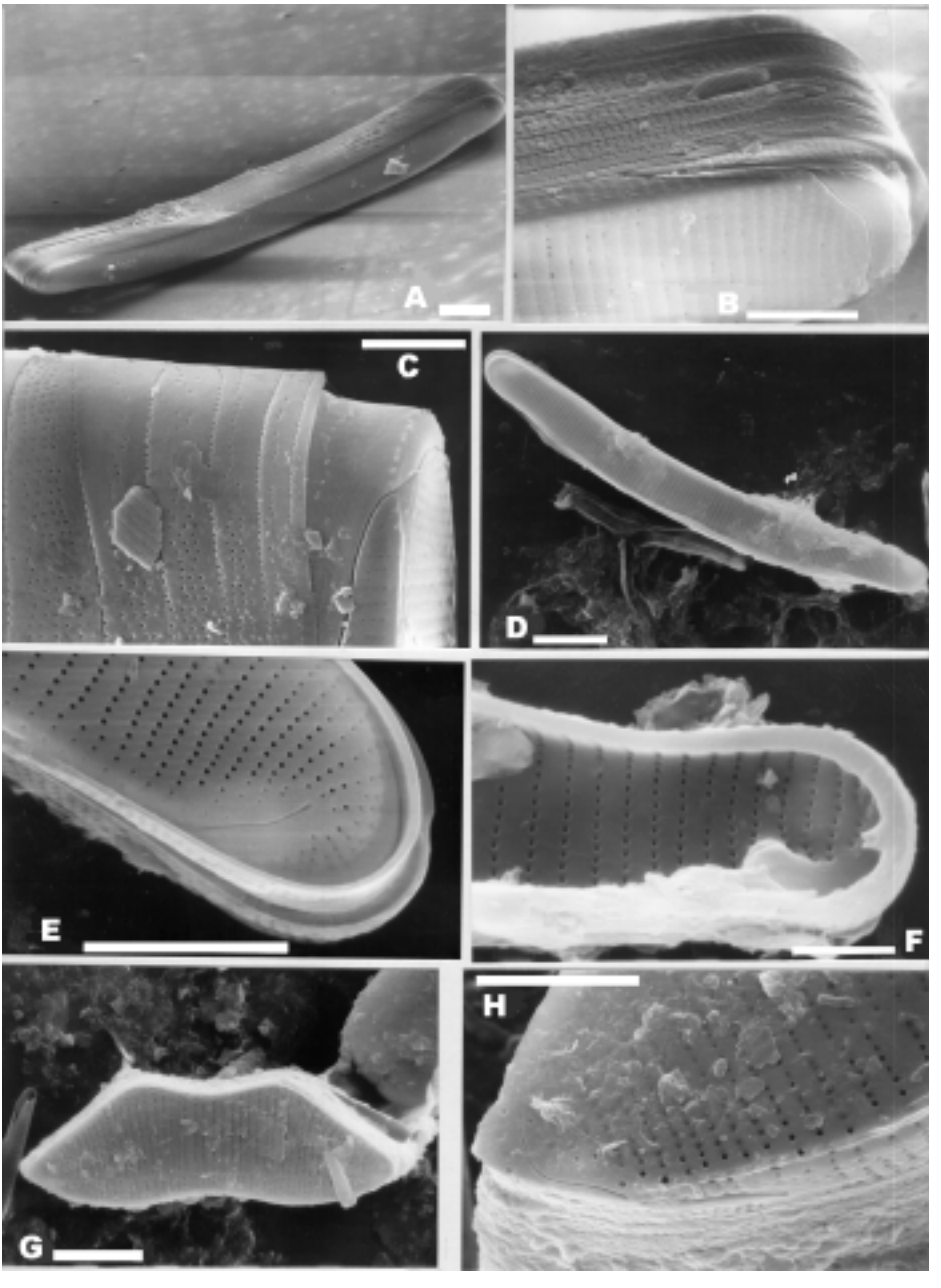

Figure 2. SEM. Scale bars: 5 μm: B-C, E-F, H; 10 μm: A, D, G.

A-C *Eunotia glacialis*. **A**: general aspect of the frustule. **B**: external valve view, detail of the striae and raphe. **C**: external valve view, detail of girdle bands and raphe. **D-F**: *Eunotia* cf. *paludosa*. **D**: external valve view. **E**: detail of raphe and striae in external valve view. **F**: Internal view, detail of rimoportula, helictoglossa and striae. **G-H**: *Eunotia guianense*. **G**: external valve view. **H**: external view, detail of raphe and striae.

no information. In the study area the specimens were collected in Tarapoto Lake (pH: 6; conductivity: 84 µS.cm^{-1} and transparency: 0.5 m).

Distribution: present in tropical and subtropical regions from South America. This is the first mention for the species in the Amazon region.

Observations: our materials were determined on the basis of characters visible with LM following the descriptions given in Frenguelli (1933).

Eunotia transfuga Metzeltin & Lange-Bertalot Figs. 3 F-H

Metzeltin & Lange-Bertalot 1998: 84, figs. 9:1-3; fig. 8: 5.

Valves isopolar, slightly arcuate with subcapitate apices. Striae uniseriate, parallel and strongly radial at the ends; interrupted by a slightly visible axial area in the ventral margin. At the valve face and mantle junction there is a row of conspicuous spines. Raphe on the mantle slightly developed at valve face. Girdle bands with seve-ral rows of poroids. Dimensions: length: 136-159 µm, breadth: 8-9 µm, striae in 10 µm: 17-18, areolae in 10 µm: 28-32, spines in 10 µm: 6.

Studied material: samples 163 and 312.

Ecology: we did not find information in the literature. In the studied area the specimens were collected in habitats with: pH: 4.8-6.6, conductivity: 10-160 µs.cm^{-1}, transparency: 0.6-0.65 m.

Distribution: this species could be endemic of the Amazon region as up to now it was found only in the Brazilian Amazon (Metzeltin & Lange-Bertalot, 1998).

Observations: in the literature the specimens are longer than those studied by us. This species is close related with *E. rabenhorstiana* var. *rabenhorstiana.* Metzeltin & Lange-Bertalot (1998) separated these species taking into account differences in pole morphology (more dilated in *E. transfuga*).

Eunotia triodon Ehrenberg Figs. 4 A-C

Ehrenberg 1837: 45.

Valves with the ventral margin concave and dorsal one with three undulations. Rounded ends differentiated from the rest of the valve. Striae uniseriate, slightly sunken, parallel in the whole valve with some shorter striae between them. Areolae circular. Raphe oblique lying mostly at the mantle, raphe endings slightly curved. Girdle bands with several rows of poroids. Dimensions: length: 37 µm; breadth: 10 µm (center); striae in 10 µm: 13; areolae in 10 µm: 35 (only one specimen measured).

Studied material: sample 329.

Ecology: prefer oligotrophic to somewhat acid water (Patrick & Reimer, 1966). In the study area collected in a lake with low pH (4.8) and extremely low conductivity (5 µS.cm^{-1}).

Distribution: Alpine regions of Northern Europe (Krammer & Lange-Bertalot, 1991). This is the first mention of the species in a tropical region. Mentioned in the Colombian Andes by West (1914).

Observations: our materials were determined on the basis of LM characters as it was not previously studied with SEM. The studied specimens are

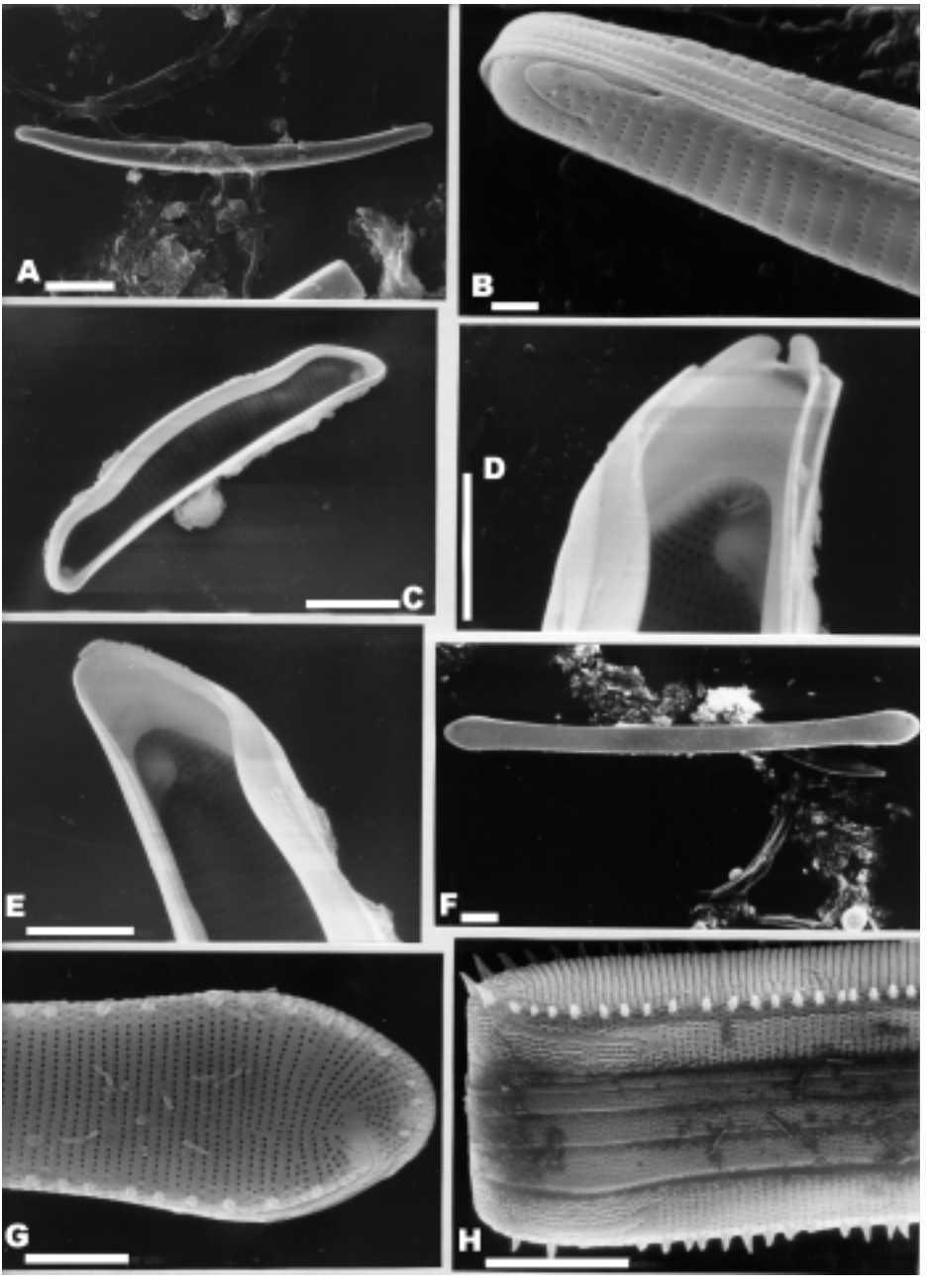

Figure 3. SEM. Scale bars: 1 µm: B, E; 5 µm: D, G; 10 µm: A, C, F, H.

A-B *Eunotia naegelli.* **A**: external valve view. **B**: detail of striae, raphe and girdle bands. **C-E** *Eunotia pseudoindica.* **C**: internal valve view. **D**: internal view, detail of rimoportula and helictoglossa. **E**: internal view of the pole without rimoportula, detail of the helictoglossa. **F-H**: *Eunotia transfuga*. **F**: external valve view. **G**: detail of the raphe and striae in external view. **H**: frustule in external view, detail of the girdle bands, striae, raphe and spines.

similar in valve outline to *E. trigibba* Hustedt, but differ from the specimens of this species illustrated in Metzeltin & Lange- Bertalot (1998), in raphe morphology. A study with SEM of the type material of these two taxa is necessary to clarify identification problems.

Eunotia zygodon* var. *compacta
Hustedt Figs. 4 D-F

Hustedt 1913 in Schmidt *et al*. 1874-1959: pl. 287, fig. 8.

Valves isopolar with ventral margins slightly concave and dorsal ones with two undulations and ends differentiated from the rest of the valve. Raphe long, well developed on the mantle, slightly curved on the valve face. Striae uniseriate, parallel, radial at the poles alternating on the dorsal margin with short striae between them. Areolae circular, visible with LM. Rimoportula on the dorsal side of the poles. Helictoglossae differentiated, with a big hyaline area. Girdle bands with several rows of poroids Dimensions: length: 68-108 µm, breadth: 14-17 µm, striae in 10 µm: 12-18, areolae in 10 µm: 25-28.

Studied material: sample 312.

Ecology: we did not find information in the literature. In the study area the specimens were collected in Amauri Creek with pH 4.8, conductivity: 10 $\mu S.cm^{-1}$ and transparency: 0.60 m.

Distribution: neotropical (Schmidt *et al.*, 1874-1959). This is the first mention of this species in the Amazon region.

Observations: the identification of our materials was based on LM characters since the only illustrations of the species are in Schmidt *et al.* (1874-1959) and Simonsen (1987).

Discussion and Conclusions

The analysis of these samples showed that the genus *Eunotia* is very well represented in this region.

Besides the ten taxa included in this paper, another eight taxa were previously reported in the study area in Sala *et al.* (2002).

Eunotia glacialis, *E. transfuga, E. paludosa, E. pseudoindica, E. naegelli* and *E. zygodon* var. *compacta* were recorded for the first time in Colombia. All of these species except *E. transfuga* were also mentioned for the first time for the Amazon region. *Eunotia triodon* has been collected from the Colombian Andes (West, 1914) but is listed here for the first time in South American lowland tropical regions. Our results and previous information suggest that, *E. anamargaritae, E. guianense, E. pseudoindica, E. transfuga* and *E. zygodon* var. *compacta* are present only in neotropical habitats while *E. camelus, E. glacialis, E. naegelli, E. paludosa* and *E. triodon* are cosmopolitan.

All the studied taxa were analyzed with SEM. The fine valve morphology of *E. anamargaritae; E. pseudoindica, E. triodon* and *E. zydodon var. compacta* is described for the first time. In the case of the other species, the comparison of our results with observations in the literature showed little differences in dimensions and details of valve morphology. Our specimens of *E. camelus* differ from others in that the raphe fissures do not reach the dorsal margin. Our specimens of *E. glacialis* differ from those described by Krammer & Lange

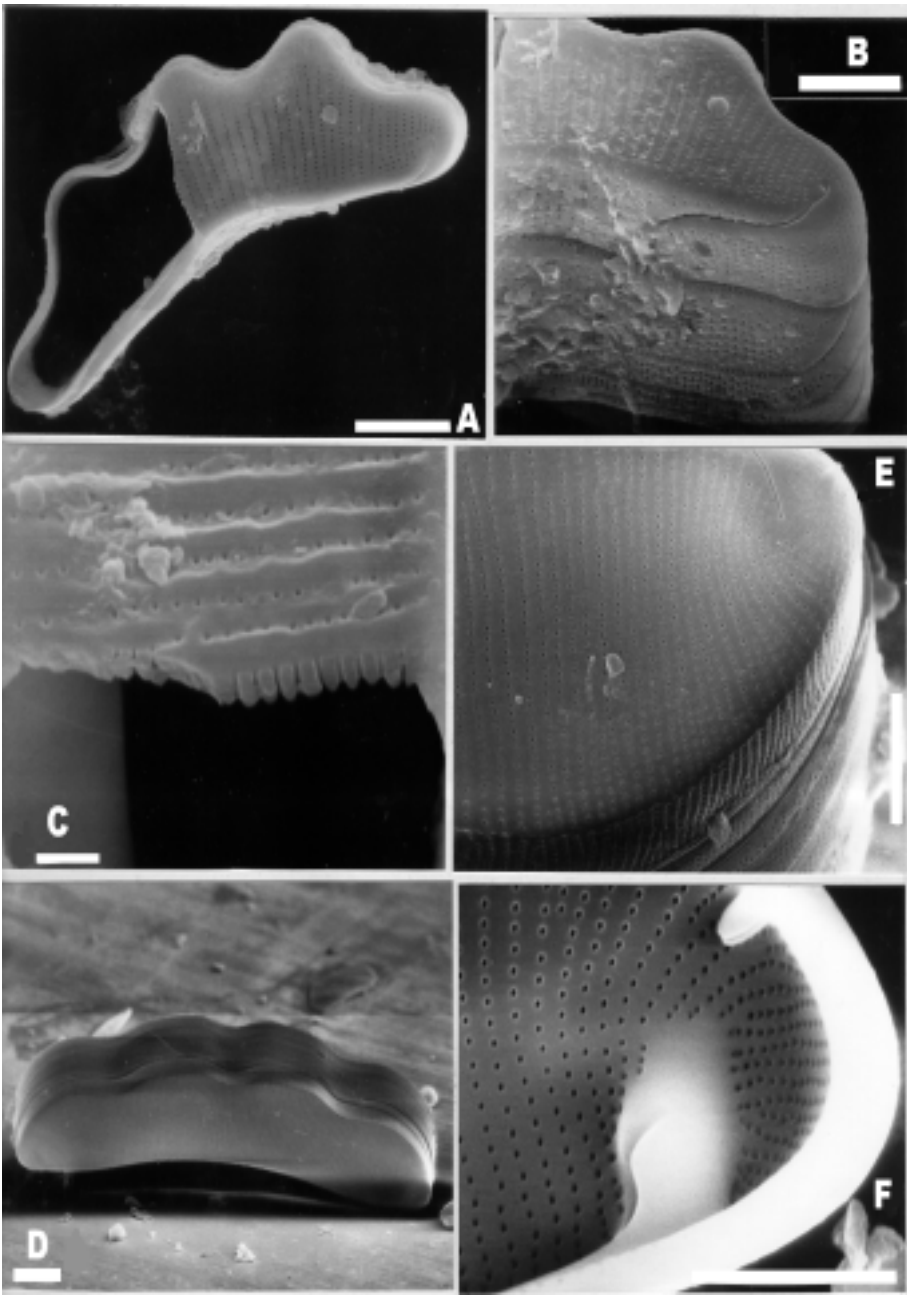

Figure 4. SEM. Scale bars: 1 µm: C, E; 5 µm: B, F: 10 µm: A, D.

A-C *Eunotia triodon*: **A**: external valve view. **B**: detail of raphe and girdle bands in external view. **C**: broken valve, detail of striae and areolae. **D-F**: *Eunotia zygodon* var. *compacta*: **D**: general aspect of a frustule. **E**: detail of striae and raphe in external view. **F**: internal valve view, detail of the rimoportula and helictoglossa.

Bertalot (1991) in the presence of a row of little spines at the valve, ends and our specimens of *E.* cf. *paludosa* are wider and have more striae in 10 µm than those described in Patrick & Reimer (1966) and Krammer & Lange *Bertalot* (1991). Nevertheless we think that these differences are not enough to consider our material as another species.

The study area is characterised by low to neutral pH, moderate conductivity with sometimes extremely low values, low transparency and high temperature. The ecological characteristics given in the literature for the majority of the studied taxa agree with our observations. There were no ecological data for three species: *E. pseudoindica* was found in a lake with low pH (6) and low conductivity (84 $\mu S.cm^{-1}$). *E. transfuga* was collected in two waterbodies with low pH (4.8-6.6) and extremely low to moderate conductivity (10- 106 $\mu S.cm^{-1}$). Finally *E. zygodon* var. *compacta* was collected in Amauri Creek, which has low pH (4.8) and extremely low conductivity (10 $\mu S.cm^{-1}$).

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