Original Research Article

Investigation of Occurrence of Diatoms (Bacillariophyta) in Hydrographic Basins of the State of Roraima, Amazon – Brazil

ABSTRACT

The objective of this research was to carry out a survey of the diatomaceous fluorula (Bacillariophyta) in the Branco River basin and its sub-basins in the State of Roraima (Amazonia, Brazil). The taxa were identified and presented on plates with photomicroscopy. The collections were always carried out in the dry periods, between December and March from 2000 to 2012. Sampling for qualitative and quantitative analysis was carried out through vertical and horizontal hauls in the marginal area of the rivers and with a bottom collection bottle. Bottom sediments and periphyton collections were also performed. The samples and permanent slides were designated for the reference collection of the National Institute for Research in the Amazon – INPA. 172 plankton samples at 43 sampling sites (20 in rivers and 23 in streams) were carried out. The low water period was characterized by slightly acidic to neutral pH, low transparency and typical clear water conductivity. Sixty-nine taxa distributed in three classes, 10 orders, 15 families and 20 genera were identified. The most representative orders were *Naviculales* (38%), *Eunotiales* (26%) and *Surirellales* (9%). The families with the highest representation were *Eunotiaceae* (26%), *Pinnulariaceae* (19%) and *Surirellaceae* (9%). The species with the highest frequency of occurrence and representativeness in the integrated river-igarapé system were: *Actinella* sp., *Aulacoseira ambigua*, *A. granulata*, *A. pseudogranulata*, *Aulacoseira* sp., *Frustulia rhomboides*, *Surirella linearis*, and *Synedra goulardii* var. *fluviatilis*.

Keywords: Diatoms; taxonomy; occurrence; distribution; Amazon

1. INTRODUCTION

Diatoms are important constituents of phytoplankton, considered protists, eukaryotes and autotrophs. According to the Round et al. [1] it belongs to the division Chromophyta (Bacillariophyta) having as main characteristic the presence of a cell wall composed of silica. The first diatoms are believed to have appeared during the Lower Jurassic, between 200 and 175 M. years [2]. Currently, there are about 250 genera and 10,000 species identified, with this number exceeding 100,000, as a result of the use of new and improved techniques of observation by electron microscopy [3].

Diatoms are found in the most varied aquatic environments, from continental lentic and lotic ecosystems to estuaries and marine environments, from peat bogs to wet and swampy soils. They may present different morphological patterns such as bacillary, circular, lozenge, sigmoidal, quadrangular, triangular, cuneiform, elliptical, oblong, elongated, stellate and lanceolate [4]. They can also present different habits such as planktonic, periphytic and benthic. As planktonic organisms, they remain suspended in water, due to adaptations such as colony formation or the presence of spines in the frustules. They can be part of the periphyton, in this case being found on rocks, plants and sandy substrate, using a raphe system and curved or arched frustules, which help in the fixation. According to the type of substrate they are classified as epipelic, episamic or epilitic. They can also be found as part of the benthic assemblage, using mucilage tubes to move on different substrates [5,6].

Diatoms are an important part of phytoplankton, exerting several functions in aquatic ecosystems, including a source of nutrients for the food net, participation in carbon flux, release of toxins and with an important participation in the production of oxygen. As active primary producers, these microorganisms produce about $2x10^{13}$ kg C/year in marine ecosystems, which represents 20 to 25% of the world's primary production [7] and 50% of marine primary production [8].

The diatom community presents seasonal organisms, which can quickly demonstrate the interactions that affect the aquatic environment, indicating the presence or not of probable environmental impacts resulting from natural cyclical variations or of anthropogenic origin. In general, the group has been little studied in Brazil, though new species are constantly described, as well as new citations are added for different regions of the country. This research aimed to identify the diatomological florula (Bacillariophyta) in the Branco River basin and its sub-basins, located in the State of Roraima (Brazilian Amazon), presenting the results in an identification list and plates with photomicroscopy.

2. STUDY AREA

Roraima is one of the most preserved states in the Brazilian Amazon. The study area comprised the sub-regions of the municipalities of Boa Vista (state capital; 2°49′10″N, 60°40′17″W); Alto Alegre (2°53′53″N, 61°29′ 29″W); Mucajaí (2°25'48''N, 60°55'11''W); Iracema (2°10'48''N, 61°02'24''W) and Cantá (02º36'18”N, 60º34'01”W; Fig. 1). The average altitude of the municipalities is 70 meters above level sea. The predominant climate in the region studied according to the Köppen-Geiger classification is Tropical Equatorial "*Af*", with emphasis on Tropical Savanna "*Aw*" with summer rains from the northern portion to the east of the state. The average annual rainfall is 1500 mm, and in the mountainous areas to the north the average rainfall can exceed 2500 mm.

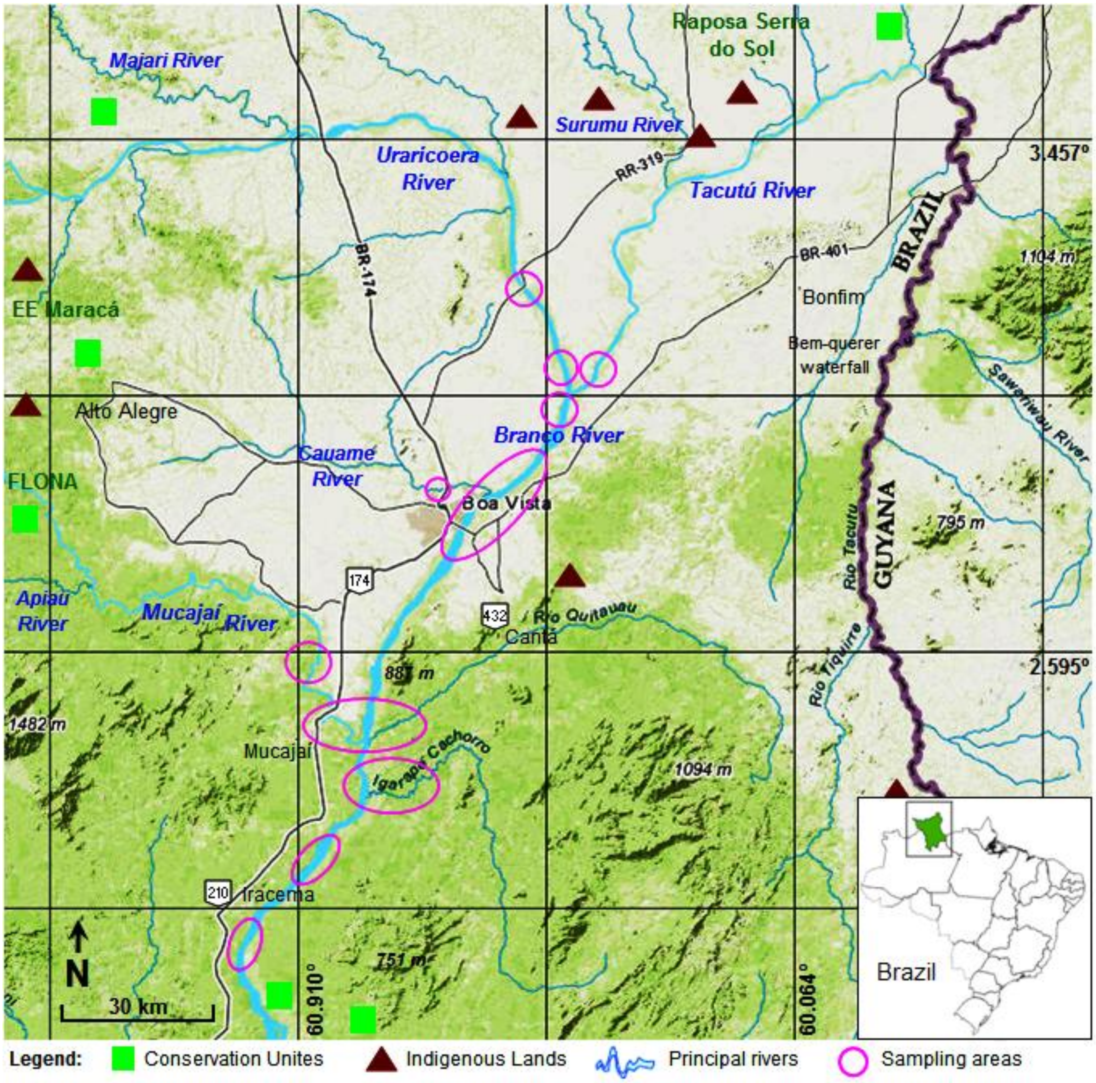

Figure 1. Study area with the location of the main geographic domains and sampling sites. Fonte: ArcGIS Web Application - © 2022 ArcGIS.

The studied region presents an immense mesh of sub-basins and streams, almost all of them well-preserved. Despite this, the absence or inadequacy of sewage work in the municipalities [9] can contribute to domestic sewage disposal into the fluvial system. The problem can be aggravated during the dry season, when the flow of the Branco River is five times lower than in the flood, reducing its purification capacity. Another activity of potential impact for the studied region is the mining activity. The regions of Alto Alegre, Iracema and Mucajaí have areas of interest for mining and extraction of sand and pebble for civil construction.

3. METHODOLOGY

For this research, 172 plankton samples from 43 points distributed in six rivers were analyzed and reviewed: Branco (8), Uraricoera (3), Tacutu (2), Cauamé (2), Mucajaí (3) and Quitauau (2), and 23 streams, located in the municipal areas of Boa Vista, Alto Alegre, Mucujaí, Iracema and Cantá (State of Roraima). Phytoplankton samples were collected during the low water period (dry season) between the months of December and March of the hydrological years 2000, 2002, 2006 and 2012. The collections were primarily carried out between 09:00 and 15:00. All material collected was preserved in Transeau solution (1:1) and stored in dark bottles. The samples and permanent slides were designated for the reference collection of the National Institute for Research in the Amazon – INPA. Subsequently, starting in 2019, all preserved material was reviewed using new optical technologies and based on new key classifications. Historical data was compared with updated real-time field measurements to ascertain possible environmental changes. Two sampling procedures were performed: 1) qualitative analysis by stratified drag and GPS-guided; and 2) quantitative analysis by surface volumetric sampling with five liters Van Dorn bottle. Surface collections, 0.5 and 1.0 meters deep were established from the determination of the euphotic zone with Secchi disk. Nylon nets measuring 30 x 70 cm, diameter of 30 cm and mesh of 20 µm and 45 µm were used. Periphyton and bottom sediments were also sampled and preserved with 1% acetic lugol's solution for analysis. Permanent slides were prepared with 10 µL of sample and fixed with Naphrax. Morphological analysis and measurements used in taxonomic typing were performed with a Zeiss phase contrast binocular microscope with 25, 40 and 100x objectives, using lugol and/or methylene blue as contrast. The identified taxa were photographed using a BX61 photomicroscope. In taxon plates, the 50 µm graphic scales for 25-40x magnification objectives were made with 1.8 and 2.8 cm, respectively. Chlorophyll-*a* was determined by the colorimetric method (664 ηm) with extraction by 90% acetone on Whatman GF-F filters, according to the procedures for biological analysis [10200 – Plankton] and [10300 – Periphyton] [10]. The score of material was done with an inverted microscope and Sedwick-Rafter's sedimentation chambers of 5 mL volume. Cells, colonies and filaments were quantified according to random fields' method. Based on the minimum area method and considering the samples with the greatest number of species, the constant number of fields were counted (n=30). The score limit has been established according to the rarefaction curve of species, having been closed once reached the total of 100 individuals of the most common species. All sample collection, analysis and conservation procedures followed recommendations from the specialized literature [10-12].

The identification system for species classification was based on the recognition of phenotypic characters, including frustula morphology; symmetry, shape, measurement and structure of the valve and apices; general layout of the raphe; presence or absence of pores and the composition of striae and areolas. The qualitative and quantitative analysis of diatoms followed the methodological procedure of Ütermohl [13]. Only individuals with intact plastids or with alterations resulting from fixation were quantified. Considering that many organisms are positioned in a connective view at the base of the chamber, which makes their identification and subsequent counting difficult, some complexes of species with similar morphologies were defined to carry out the counting in the chamber. For the definition of abundant and dominant species, criteria established in the literature were used [14]. To identify genera and species, classical works, monographs, reviews and floras with identification keys were consulted [1,15-23]. Subsequently, all nomenclature was revised with the more recent classification, based on the *AlgaeBase* electronic taxonomic system [24].

4. RESULTS AND DISCUSSION

4.1 Ecological patterns

Although the number of publications on planktonic taxonomy in the Amazon is relatively modest, when compared to the subtropical and temperate regions, it is already possible to observe a tendency towards the predominance of two large divisions, depending on the richness and number of infraspecific categories: Chlorophyta and Bacillariophyta. From Haeckel's classic bipartite classification at the end of the 19th century, to the review by Round et al. [1], who established a classification based on morphological (centric or pennate) and symmetrical (radial or bilateral) patterns, an adequate classification was drived for the Bacillariophyta division, particularly to diatoms. Based on the recent molecular analysis, a reclassification was established, allowing the division of Bacillariophyta into two large monophyletic clades (Coscinodiscophytina and Bacillariophytina) with three classes: *Coscinodiscophyceae*, *Bacillariophyceae* and *Mediophyceae* [25,26], classification adopted in this study.

Within the Bacillariophyta division, 69 taxa with 20 genera and eight varieties were identified, distributed in three classes, 10 orders and 15 families. The predominant class was *Bacillariophyceae* with an abundance of 89.9%, predominating in both rivers and streams. The most representative orders were *Naviculales* (37.7%) and *Eunotiales* (26.1%). The families with the highest representation were *Eunotiaceae* (26.1%) and *Pinnulariaceae*

(18.8%) (Figs. 2 and 3). Diatoms are among the most abundant and diverse planktonic groups. In the late 1970s, Uherkovich and Franken [18] already suggested that the diatom group was abundant, well distributed and with high species richness in the Amazon, after identifying in the Negro River basin 146 taxa of this group in a total of 329 taxa, 44.4% of the total. More recently, Metzeltin and Lange-Bertalot [27] described 179 new diatom taxa, most of them from the Amazon. Analyzing samples from different environments of the Brazilian flora, with emphasis on the black waters of the Amazon region, Ferrari et al. [22] suggested that genera of the Eunotiaceae family are the most common Bacillariophyta in Brazilian flora, especially *Eunotia* and *Actinella*. Despite this, the species with the highest frequency of occurrence in both systems (river and stream) did not include taxa from this family, except for *Actinella* sp. The most representative species in the integrated river-streams system were *Actinella* sp., *Aulacoseira ambigua*, *A. granulata*, *A. pseudogranulata*, *Aulacoseira* sp.,*Frustulia rhomboides*, *Surirella linearis*, *Synedra goulardii* var. *fluviatilis*.

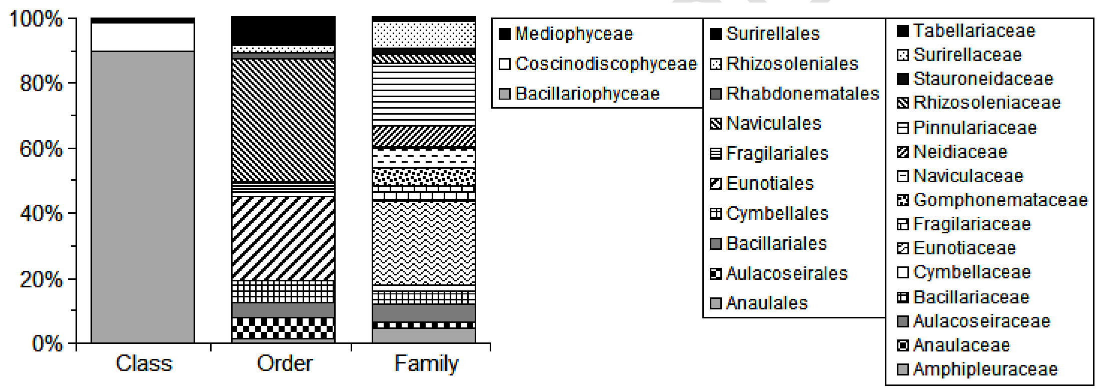

Figure 2. Total abundance of taxa grouped by class, order and family in the integrated river-stream system of the Branco River basin (RR) during low water periods (N=69 taxa).

On dominance, 15 taxa were identified in the rivers: *Actinella* sp., *Aulacoseira ambígua* (Grunow) Simonsen, *A. granulata* (Ehrenberg) Simonsen, *Aulacoseira* sp., *Eunotia asterionelloides* Hustedt, *Eunotia zygodon*, *Frustulia rhomboides*, *Gomphonema gracile*, *Pinnularia acrosphaeria*, *P. braunii*, *Stauroneis anceps*, *Surirella biseriata*, *S. linearis*, *Synedra goulardii* var. fluviatilis (Lemmermann) Frenguelli and *Tabellaria fenestrata* (Lyngbye) Kützing. In the streams, 14 dominance were observed: *Actinella mirabilis*, *Aulacoseira ambigua*, *A. granulata*, *Aulacoseira* sp., *Cymbella amphicephala* Näegeli ex Kützing, *Eunotia didyma* Grunow ex Zimmermann, *E. flexuosa*, *E. serra*, *Frustulia rhomboides*, *Neidium affine*, *N. bisulcatum*, *Rhizosolenia eriensis* H.L.Smith [*Urosolenia eriensis* (H.L.Smith) Round & R.M.Crawford], *R. longiseta* O.Zacharias [*Urosolenia longiseta*

(O.Zacharias) Edlund & Stoermer] and *Surirella linearis*. The complete list of species, including varieties, with indication of presence, dominance and frequency of occurrence for rivers and streams are presented in Tables 1 and 2.

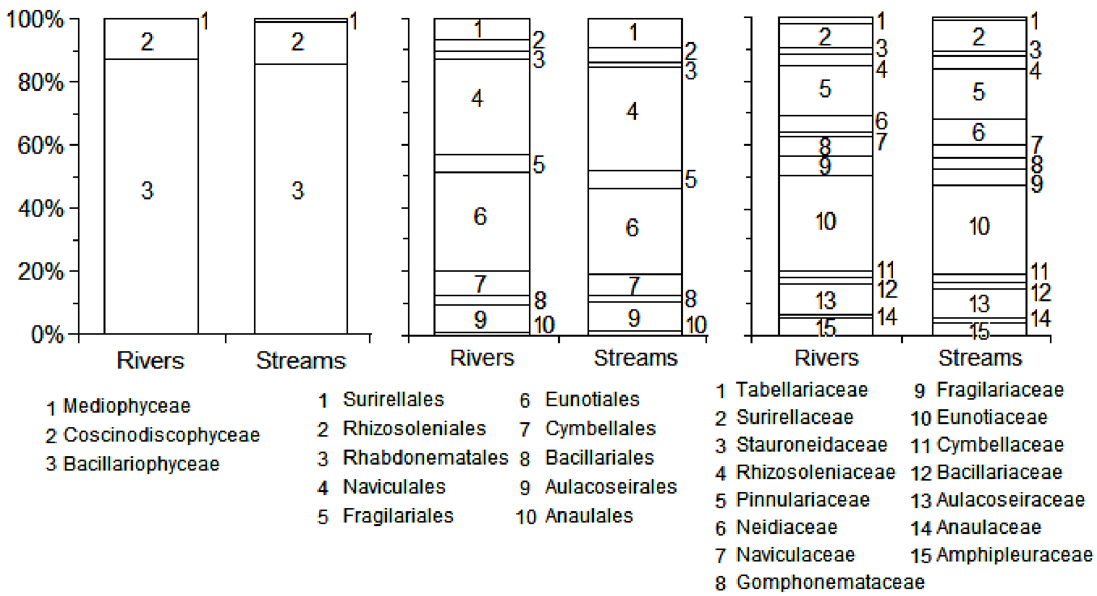

Figure 3. Presence and dominance of taxa grouped by class, order and family in the rivers and streams of the Branco River basin (RR) during low water periods.

Table 1. Distribution of taxa with indication of frequency (F%) and constancy index by species at sampling sites of rivers in the Branco River basin, Roraima, Brazil.

	Bra								Ura			Tac		Cau		Muc			Qui		F
	B1	B2	B3	B4	B5	B6	B7	B8	U1	U2	U3	T1	T2	C1	C2	M1	M2	M3	Q1	Q2	(%)
Actinella mirabilis Grunow	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x			80
Actinella sp.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	d	d	d	x	x	100
Aulacoseira ambigua (Grunow) Simonsen	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	d	d	100
Aulacoseira granulata (Ehrenberg) Simonsen	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	d	d	100
Aulacoseira pseudogranulata (A.Cleve) Simonsen	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	100
Aulacoseira sp.	d	d	x	x	x	x	x	x	d	d	d	d	d	x	x	x	x	x	d	d	100
Cymbella amphicephala Näegeli ex Kützing	x	x	x	x	x	x	x	x	x	x	x					x	x	x			70
Desmogonium femoriforme R.M. Patrick	x	x	x	x	x	x	x	x	x	x	x					x	x	x			70
Eunotia arcus Ehrenberg	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x			80
Eunotia asterionelloides Hustedt	d	d	d	d	d	d	d	x	d	d	d	d	d	d	d	d	d	d	x	x	100
Eunotia bilunaris var. *mucophila* Lange-Bertalot, Nörpel-Schempp & E. Alles							x									x			x	x	20
Eunotia didyma var. *claviculata* Hustedt ex Simonsen						x	x							x		x			x	x	30
Eunotia didyma var. *didyma* Grunow ex Zimmermann						x	x							x		x			x	x	30
Eunotia didyma Grunow ex Zimmermann	x	x	x	x	x	x	x	x	x	x	x					x	x	x			70
Eunotia flexuosa (Brébisson ex Kützing) Kützing	x	x	x	x	x	x	x	x	x	x	x					x	x	x			70
Eunotia grunowii f. *uplandica* A. Cleve	x	x	x	x	x	x	x	x	x	x	x					x	x	x			70
Eunotia intermedia (Krasske ex Hustedt) Nörpel & Lange-Bertalot	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	90
Eunotia lineolata Hustedt	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x			80
Eunotia praerupta Ehrenberg	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	90
Eunotia serra Ehrenberg	x								x	x	x	x	x			x	x	x			45
Eunotia triodon Ehrenberg	x	x	x	x	x	x	x	x	x	x	x	x	x								65
Eunotia zygodon Ehrenberg	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100
Eunotia zygodon var. *elongata* Hustedt ex Simonsen	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	100
Fragilaria tenera (W.Smith) Lange-Bertalot	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x			80
Fragilaria ulna (Nitzsch) Lange-Bertalot	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x			80
Frustulia rhomboides (Ehrenberg) De Toni	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100
Frustulia rhomboides var. *crassinervia* (Brébisson ex W. Smith) Ross	x	x	x	x	x	x	x	x	x	x	x					x	x	x			70
Frustulia rhomboides var. *saxonica* (Rabenhorst) De Toni	x	x	x	x	x	x	x	x	x	x	x					x	x	x			70
Gomphonema acuminatum Ehrenberg	x	x	x	x					x	x	x	x	x								45
Gomphonema augur Ehrenberg	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			90
Gomphonema gracile Ehrenberg	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100

Legend: x=presence; d=dominance; Bra= Branco; Ura= Uraricoera; Tac= Tacutu; Cau= Cauamé; Muc= Mucajaí and Qui= Quitauau rivers.

Table 1. Distribution of taxa with indication of frequency (F%) and constancy index by species at sampling sites of rivers (continuation).

	Bra								**Ura**			**Tac**		**Cau**		**Muc**			**Qui**		**F**
	B1	B2	B3	B4	B5	B6	B7	B8	U1	U2	U3	T1	T2	C1	C2	M1	M2	M3	Q1	Q2	(%)
Gomphonema subtile Ehrenberg	x	x	x						x	x	x	x	x								40
Gyrosigma scalproides (Rabenhorst) Cleve	x	x	x						x	x	x										30
Navicula crucicula (W. Smith) Donkin						x	x	x											x	x	25
Navicula sp. (1)																					0
Navicula sp. (2)																					0
Neidium affine (Ehrenberg) Pfitzer						x	x	x						x	x	x	x	x	x	x	50
Neidium binode (Ehrenberg) Hustedt	x					x	x	x						x	x	x	x	x			45
Neidium bisulcatum (Lagerstedt) Cleve	x	x				x	x	x	x					x	x						40
Neidium dubium (Ehenberg) Cleve	x	x				x	x	x	x					x	x	x	x	x			55
Neidium sp.	x											x	x								15
Nitzschia acicularis (Kützing) W.Smith						x	x	x						x	x	x	x	x			40
Nitzschia tryblionella Hantzsch						x	x	x						x	x	x	x	x			40
Nitzschia vermicularis (Kützing) Hantzsch						x	x	x						x	x						25
Pinnularia acrosphaeria (Brébisson) Rabenhorst	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100
Pinnularia braunii Cleve	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100
Pinnularia cardinaliculus Cleve	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	100
Pinnularia divergens W. Smith	x						x	x				x		x	x	x	x	x			45
Pinnularia episcopalis Cleve	x	x					x	x	x			x		x	x	x	x	x			55
Pinnularia gibba (Ehrenberg) Ehrenberg	x	x				x	x		x			x									30
Pinnularia legumen var. legumen Ehrenberg	x	x	x						x			x									25
Pinnularia major (Kützing) Rabenhorst	x					x	x	x	x					x	x	x	x	x			50
Pinnularia nobilis (Ehrenberg) Ehrenberg							x	x											x	x	20
Pinnularia platycephala (Ehrenberg) Cleve	x	x							x												15
Pinnularia polyonca (Brébisson) W. Smith	x	x					x	x	x										x	x	35
Pinnularia sp. (1)	x	x			x	x	x	x	x			x				x	x	x	x	x	65
Pinnularia sp. (2)	x	x			x		x					x							x	x	35
Rhizosolenia eriensis H.L.Smith	x	x			x	x	x	x	x			x		x	x	x	x	x	x	x	75
Rhizosolenia longiseta O.Zacharias	x	x			x	x	x	x	x			x		x	x	x	x	x	x	x	75
Stauroneis anceps Ehrenberg	d	d	d	d	x	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100
Stenopterobia delicatissima (F.W.Lewis) Brébisson ex Van Heurck						x	x	x								x	x	x	x	x	40
Surirella biseriata Brébisson	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	x	x	100
Surirella didyma Kützing	x	x	x						x			x									25
Surirella elegans Ehrenberg	x	x	x						x			x									25
Surirella lapponica A. Cleve	x	x	x						x			x									25
Surirella linearis W. Smith	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100
Synedra goulardii var. fluviatilis (Lemmermann) Frenguelli	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100
Tabellaria fenestrata (Lyngbye) Kützing	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100
Terpsinoë musica Ehrenberg	x	x							x												15

Legend: x=presence; d=dominance; Bra= Branco; Ura= Uraricoera; Tac= Tacutu; Cau= Cauamé; Muc= Mucajaí and Qui= Quitauau rivers.

Table 2. Distribution of taxa with indication of frequency (F%) and constancy index by species at sampling sites in the streams of the Branco River basin, Roraima, Brazil.

	Bva						**Aal**				**Muc**					**Ira**			**Can**					**F**
	V1	V2	V3	V4	V5	V6	A1	A2	A3	A4	J1	J2	J3	J4	J5	I1	I2	I3	N1	N2	N3	N4	N5	(%)
Actinella mirabilis	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100
Actinella sp.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	100
Aulacoseira ambigua	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100
Aulacoseira granulata	d	d	d	d	d	d	d	d	d	x	d	d	d	d	d	d	d	d	d	d	d	x	d	100
Aulacoseira pseudogranulata	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	100
Aulacoseira sp.	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	x	x	x	x	x	x	x	x	100
Cymbella amphicephala	d	d	d	d	d	d	d	d	d	d	x	x	x	x	x									65
Desmogonium femoriforme	x	x	x	x	x	x	x	x	x	x														43
Eunotia arcus	x	x	x	x	x	x	x	x	x	x	x	x	x	x										61
Eunotia asterionelloides	x	x	x	x	x	x	x	x	x	x														43
Eunotia bilunaris var. *mucophila*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x						70
Eunotia didyma var. *claviculata*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	91
Eunotia didyma var. *didyma*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Eunotia didyma	d	d	d	d	d	x	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	100
Eunotia flexuosa	d	d	d	d	d	x	d	d	d	d	d	d	d	x	d	d	d	d	d	d	d	d	d	100
Eunotia grunowii f. *uplandica*	x	x	x	x	x	x	x	x	x	x						x	x	x						57
Eunotia intermedia	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Eunotia lineolata	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Eunotia praerupta	x	x	x	x	x	x	x	x	x	x						x	x	x						57
Eunotia serra	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	x	d	d	100
Eunotia triodon	x	x	x	x	x	x	x	x	x	x														43
Eunotia zygodon																								0
Eunotia zygodon var. *elongata*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Fragilaria tenera											x	x	x	x	x	x	x	x	x	x	x	x	x	57
Fragilaria ulna	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Frustulia rhomboides	d	d	d	d	d	d	d	d	d	d	d	d	d	d	x	d	d	d	d	d	d	d	d	100
Frustulia rhomboides var. *crassinervia*	x	x	x	x	x	x	x	x	x	x														43
Frustulia rhomboides var. *saxonica*	x	x	x	x	x	x																		26
Gomphonema acuminatum	x	x	x	x	x	x	x	x	x	x														43
Gomphonema augur	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Gomphonema gracile																								0
Gomphonema subtile	x	x	x	x	x	x	x	x	x	x														43
Gyrosigma scalproides	x	x	x	x	x	x	x	x	x	x														43
Navicula crucicula	x	x	x	x	x	x													x	x	x	x	x	48
Navicula sp. (1)	x	x	x	x	x	x	x	x	x	x														43
Navicula sp. (2)							x	x	x	x	x	x	x	x	x									39
Neidium affine	d	d	d	d	d	d	d	d	d	d	d	d	d	d	x	d	d	d	d	d	d	d	d	100

Legend: x=presence; d=dominance; Bva= Boas Vista; Aal= Alto Alegre; Muc= Mucajaí; Ira= Iracema and Can= Cantá streams.

Table 2. Distribution of taxa with indication of frequency (F%) and constancy index by species at sampling sites in the streams (continuation).

	Bva						Aal				Muc					Ira			Can					F
	V1	V2	V3	V4	V5	V6	A1	A2	A3	A4	J1	J2	J3	J4	J5	I1	I2	I3	N1	N2	N3	N4	N5	(%)
Neidium binode																								0
Neidium bisulcatum	d	d	d	d	d	x	d	d	d	d	d	d	d	d	x	d	d	d	d	d	d	d	d	100
Neidium dubium	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Neidium sp.	x	x	x	x	x	x	x	x	x	x									x	x	x	x	x	65
Nitzschia acicularis							x	x	x	x	x	x	x	x	x	x	x	x						52
Nitzschia tryblionella							x	x	x	x														17
Nitzschia vermicularis							x	x	x	x	x	x	x	x	x									39
Pinnularia acrosphaeria	x	x	x	x	x	x	x	x	x	x									x	x	x	x	x	65
Pinnularia braunii	x	x	x	x	x	x	x	x	x	x									x	x	x	x	x	65
Pinnularia cardinaliculus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Pinnularia divergens											x	x	x	x	x	x	x	x						35
Pinnularia episcopalis	x	x	x	x	x	x	x	x	x	x														43
Pinnularia gibba	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Pinnularia legumen var. legumen	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Pinnularia major	x	x	x	x	x	x					x	x	x	x	x									48
Pinnularia nobilis	x	x	x	x	x	x	x	x	x	x									x	x	x	x	x	65
Pinnularia platycephala	x	x	x	x	x	x																		26
Pinnularia polyonca	x	x	x	x	x	x													x	x	x	x	x	48
Pinnularia sp. (1)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Pinnularia sp. (2)	x	x	x	x					x	x			x	x	x									39
Rhizosolenia eriensis	d	d	d	d	d	x	d	d	d	d	x	x	x	x	x	x	x	x	x	x	x	x	x	100
Rhizosolenia longiseta	d	d	d	d	x	d	d	d	d	d	x	x	x	x	x	x	x	x	x	x	x	x	x	100
Stauroneis anceps	x	x	x	x	x	x	x	x	x	x														43
Stenopterobia delicatissima	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	100
Surirella biseriata	x	x	x	x	x	x	x	x	x	x														43
Surirella didyma	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Surirella elegans	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									65
Surirella lapponica	x	x	x	x	x	x	x	x	x	x														43
Surirella linearis	d	d	d	d	x	x	d	d	d	d	x	x	x	x	x	x	x	x	d	d	d	d	d	100
Synedra goulardii var. fluviatilis	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	100
Tabellaria fenestrata	x	x	x	x	x	x	x	x	x	x														43
Terpsinoë musica	x	x	x	x	x	x										x	x	x						39

Legend: x=presence; d=dominance; Bva= Boas Vista; Aal= Alto Alegre; Muc= Mucajaí; Ira= Iracema and Can= Cantá streams.

4.2 Characteristics of the identified groups

Since they emerged around 250 million years ago, bacillariophytes have spread across the planet, becoming abundant in aquatic ecosystems and wet soils. This highly cosmopolitan group may be associated with other organisms, remaining distributed throughout the water column and surface sediment. Diatoms represent one of the main groups of primary producers in aquatic ecosystems [28], presenting evolutionary characteristics that made them tolerant to a wide range of pH, salinity and ionic composition [29,30]. An important evolutionary factor for most planktonic diatoms is the ability of the cells to settle, considering that these organisms are denser than other phytoplanktonic groups. Sedimentation can be considered an important evolutionary strategy for diatoms, allowing the organisms to come into direct contact with the source of minerals and ions present in the bottom sediment, especially carbonates and silicates. In addition, the excessive storage capacity of phosphorus by this group (luxury consumption), which has already been well documented in research, allows its establishment both in eutrophic environments and in oligotrophic systems. This strategy may help to explain why the density of the group remained constant both in the more preserved environments north of the Branco River basin, and in areas of urban influence within the municipality of Boa Vista.

The growth of planktonic biomass depends on natural factors such as the action of winds and rain, which generate a break in stratification, allowing the recirculation of bottom waters to the surface, stimulating the transport of cells to the epilimnion (photic zone). With the end of the low waters and the peak of the flood (June and July), the rains and strong local winds contribute to the recirculation of the deeper layers of the lakes and streams. Another important evolutionary strategy is the formation of resistance cells (statospores), which allow taxa to develop in anoxic environments or in low oxygen concentration in the hypolimnion, especially in stratified environments, a very common condition in Amazonian lotic and lentic ecosystems. The acidification of the waters by the decomposition of organic matter and the consequent formation of humic compounds, very present in the igapós, lakes and black water streams in the Amazon, are generally a controlling factor of both richness and planktonic density. In the case of bacillariophytes, the statospores allow good resistance to the low pH levels of black water, allowing the development of communities in such environments. This was especially observed in the black water streams of the Cauamé River sub-basin, in the stretch above the meeting of its waters with the Branco River. Light intensity is the preponderant factor in the development of photosynthetic communities. In this sense, the cerrado streams presented, in general, a higher population density than the forest streams, which are shaded by the surrounding forest. Evidence of this influence was observed in the results of higher chlorophyll-*a* contents in the cerrado streams located in the Uraricoera, Tacutú and Branco rivers (Clh-*a* > 2.0 µg/).

Diatoms showed high population density, especially among dominant taxa such as *Actinella* sp., *Aulacoseira* sp., *A. ambigua*, *A. granulata*, *Frustulia rhomboides*, *Surirella linearis* and *Synedra goulardii* var. *fluviatilis*. Coscinodiscophyceae, especially the genus *Aulacoseira*, have a wide distribution in aquatic ecosystems, being quite tolerant of salinity variation (eurihalines) [17,30,31], and can be found from freshwater lakes to saltwater areas, including lagoons, estuaries and areas of tide. Plates 1 to 4 (Annexes) present the taxa identified through photomicroscopy, with the official and [eventually accepted] nomenclature. Bacillariophyta diatoms were observed in different habitats in the studied aquatic ecosystems, being distributed in the water column, associated with the sediment or in submerged substrates, being part of the epiphyton, epilithon, epipelon and epipsammon communities. Associations of bacillariophytes with cyanobacteria and phytoperiphyton were also observed, which may represent a strategy for the absorption and storage of nutrients, especially phosphorus and nitrogen [1,22,30].

For all the mechanisms and strategies observed, as well as for the high frequency of occurrence in the studied environments, the importance of bacillariophytes in the networks of ecological interactions in the Northern Peripheral Amazon can be evidenced. Diatoms, especially benthic groups, are important indicators of environmental changes, including changes in pH and evidence of eutrophication [29,30,32-35]. Its high resistance to limnological variations has allowed this group to establish itself in toxic blooms and as invasive species. The region close to urban areas shows signs of pollution due to the natural growth of the urbanization process. Such events reflect on the quality of the waters, especially of the streams, in periods of drought. Sparse mining activities were also identified, especially in the southernmost region of the drainage basin. Despite this, until the completion of this study, no significant evidence of environmental impact was observed, nor the influence of domestic sewage discharge on the occurrence, distribution and frequency of planktonic organisms. The conclusion was established based on limnological data, highlighting pH, conductivity, oxygen concentration and biochemical oxygen demand, as well as the frequency pattern of occurrence and dominance of the diatom group. This can be explained both by the fact that the study area is well preserved, and by the difficulty of accessing the region by land and river.

CONCLUSION

For this research, 172 plankton samples from 43 points distributed in six rivers and 23 streams were analyzed and reviewed. Sixty-nine taxa distributed in three classes, 10 orders, 15 families and 20 genera were identified. The most representative families were

Eunotiaceae (26%), *Pinnulariaceae* (19%) and *Surirellaceae* (9%). The species with the highest frequency of occurrence and representativeness in the integrated river-stream system were: *Actinella* sp., *Aulacoseira ambigua*, *A. granulata*, *A. pseudogranulata*, *Aulacoseira* sp.,*Frustulia rhomboides*, *Surirella linearis*, and *Synedra goulardii* var. *fluviatilis*.

In the methodological aspect, the similarity in the ocorrence and distribution in rivers and strems suggests that the qualitative and quantitative sampling procedures were satisfactory and representative. There was similarity in the composition and distribution of taxa, with significant constancy of frequency and abundance of species. Evolutionary strategies, such as the sedimentation capacity and the formation of statospores, allowed the development and wide distribution of diatoms in all analyzed environments, including water layers with a tendency to anoxia. Vertical circulation also contributed to the transport and distribution of cells between the epilimnion and hypolimnion, especially between the end of the ebb and the beginning of the flood, although this cycle works differently in small rivers and streams.

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Annexes

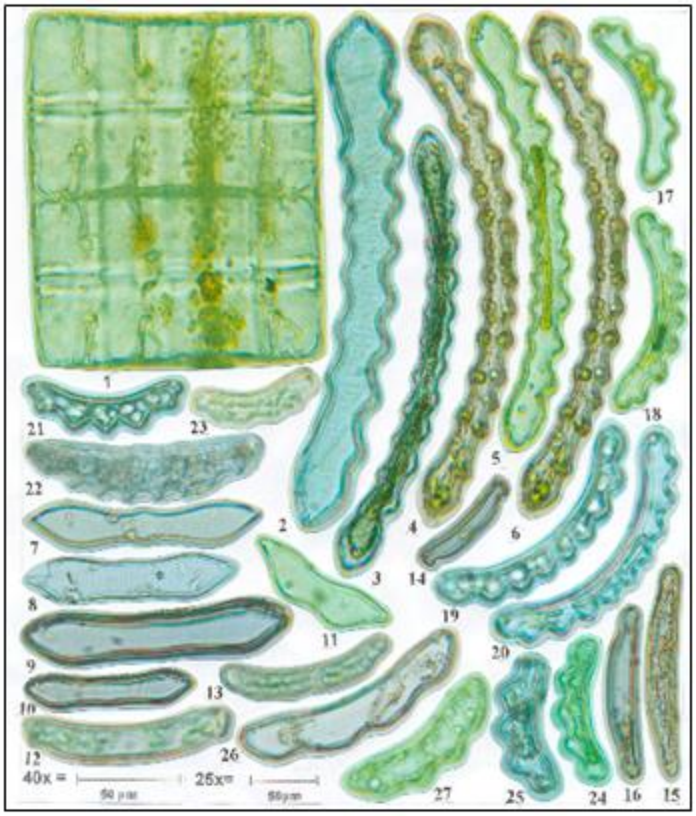

Plate 1. Fig. 1 *Terpsinoë musica* Ehrenberg (40x); Figs. 2-6 *Actinella mirabilis* Grunow (40x-25x); Figs. 7-10 *Eunotia didyma* var. *claviculata* Hustedt ex Simonsen (40x); Fig. 11 *E. didyma* var. *didyma* Grunow ex Zimmermann (40x); Figs. 12-14 *E. praerupta* Ehrenberg (40x); Fig. 15 *E. arcus* Ehrenberg (40x); Fig. 16 *E. grunowii* f. *uplandica* A. Cleve (40x); Figs. 17-23 *E. serra* Ehrenberg (40x); Figs. 24-25 *E. triodon* Ehrenberg (40x); Fig. 26 *E. zygodon* Ehrenberg (40x); Fig. 27 *E. zygodon* var. *elongata* Hustedt ex Simonsen (40x).

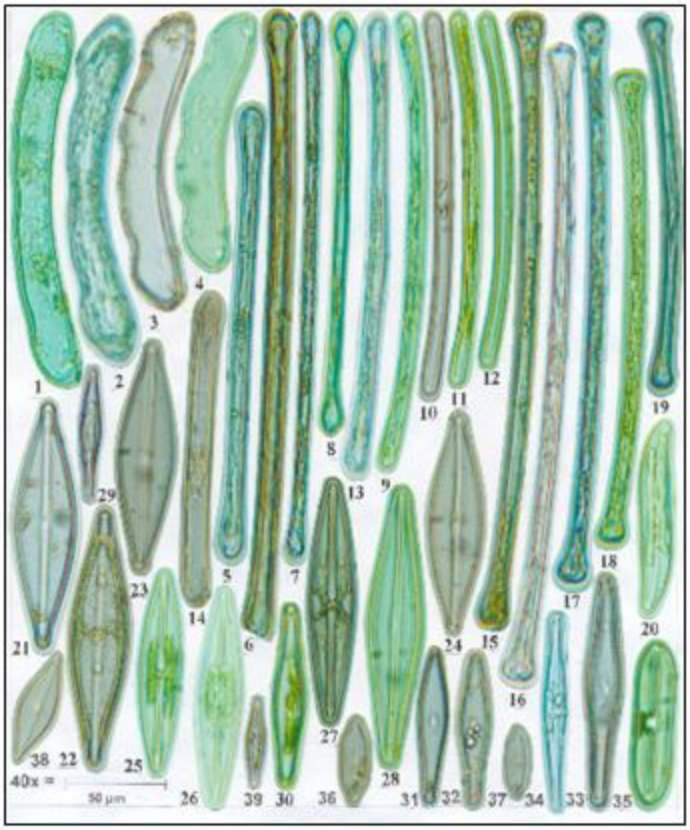

Plate 2. Figs. 1-4 *Eunotia zygodon* var. *elongata* (40x); Figs. 5-8 *E. flexuosa* (Brébisson ex Kützing) Kützing (40x); Figs. 9-12 *E. bilunaris* var. *mucophila* Lange-Bertalot, Nörpel-Schempp & E. Alles [*E. mucophila* (Lange-Bertalot, Nörpel-Schempp & Alles) Lange-Bertalot] (40x); Fig. 13 *E. intermedia* (Krasske ex Hustedt) Nörpel & Lange-Bertalot (40x); Fig. 14 *E. lineolata* Hustedt (40x); Figs. 15-19 *Desmogonium femoriforme* R.M. Patrick [*Eunotia femoriformis* (R.M. Patrick) Hustedt] (40x); Fig. 20 *Gyrosigma scalproides* (Rabenhorst) Cleve (40x); Figs 21-24 *Frustulia rhomboides* var. *saxonica* (Rabenhorst) De Toni [*F. saxonica* Rabenhorst] (40x); Figs. 25-28 *F. rhomboides* var. *crassinervia* (Brébisson ex W. Smith) Ross [*F. crassinervia* (Brébisson ex W. Smith) Lange-Bertalot & Krammer] (40x); Figs. 29-32 *Gomphonema gracile* Ehrenberg (40x); Fig. 33 *G. acuminatum* Ehrenberg (40x); Fig. 34 *G. subtile* Ehrenberg (40x); Fig. 35 *Neidium bisulcatum* (Lagerstedt) Cleve (40x); Figs. 36-37 *N. dubium* (Ehenberg) Cleve (40x); Fig. 38 *Navicula crucicula* (W. Smith) Donkin [*Prestauroneis crucicula* (W. Smith) Genkal & Yarushina] (40x); Fig. 39 *Navicula* sp. (1) (40x). [Current accepted name (if different)].

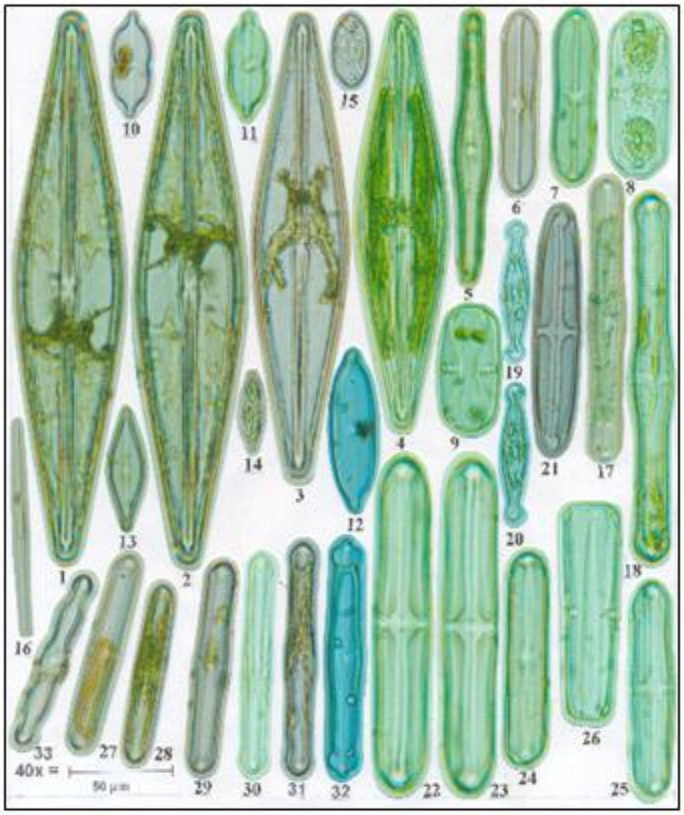

Plate 3. Figs. 1-4 *Frustulia rhomboides* (Ehrenberg) De Toni (40x); Fig. 5 *Gomphonema acuminatum* Ehrenberg (40x); Figs. 6-7 *Neidium bisulcatum* (40x); Figs. 8-9 *N. affine* (Ehrenberg) Pfitzer (40x); Figs. 10-11 *N. binode* (Ehrenberg) Hustedt [*Neidiomorpha binodis* (Ehrenberg) M. Cantonati, Lange-Bertalot & N.Angeli] (40x); Fig. 12 *Neidium* sp. (40x); Fig. 13 *Navicula crucicula* (W. Smith) Donkin [*Prestauroneis crucicula* (W. Smith) Genkal & Yarushina] (40x); Fig. 14 *Navicula* sp. (2) (40x); Fig. 15 *Nitzschia tryblionella* Hantzsch [*Tryblionella hantzschiana* Grunow] (40x); Fig. 16 *N. vermicularis* (Kützing) Hantzsch (40x); Figs. 17-18 *Pinnularia acrosphaeria* (Brébisson) Rabenhorst [*P. gibbiformis* Krammer] (40x); Figs. 19-20 *P. braunii* Cleve [*P. brauniana* (Grunow) Studnicka] (40x); Fig. 21 *P. divergens* W. Smith (40x); Figs. 22-23 *P. cardinaliculus* Cleve (40x); Figs. 24-26 *P. episcopalis* Cleve (40x); Figs. 27-31 *P. gibba* (Ehrenberg) Ehrenberg [*Rhopalodia gibba* (Ehrenberg) O. Müller] (40x); Fig. 32 *Pinnularia* sp. (40x); Fig. 33 *P. polyonca* (Brébisson) W. Smith (40x). [Current accepted name (if different)].

Plate 4. Fig. 1 *Pinnularia legumen* var. *legumen* Ehrenberg (40x); Figs. 2-5 *P. major* (Kützing) Rabenhorst (40x); Fig. 6 *P. nobilis* (Ehrenberg) Ehrenberg (40x); Figs. 7-8 *P. platycephala* (Ehrenberg) Cleve (40x); Figs. 9-12 *P. polyonca* (Brébisson) W. Smith (40x); Figs. 13-17 *Stauroneis anceps* Ehrenberg (40x); Figs. 18-19 *Stenopterobia delicatissima* (F.W. Lewis) Brébisson ex Van Heurck [*Iconella delicatissima* (F.W. Lewis) Ruck & Nakov] (40x); Fig. 20 *Surirella biseriata* Brébisson [*Iconella biseriata* (Brébisson) Ruck & Nakov] (40x); Figs. 21-23 *S. didyma* Kützing (40x); Fig. 24 *S. elegans* Ehrenberg (40x); Figs. 25-26 *S. lapponica* A. Cleve (40x); Figs. 27-28 *S. linearis* W. Smith [*Iconella linearis* (W. Smith) Ruck & Nakov] (40x). [Current accepted name (if different)].