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Phytoplankton of two rivers in the eastern Amazon: characterization of biodiversity and new occurrences[1]

Elane Domênica de Souza Cunha[2,4], Alan Cavalcanti da Cunha[2], Arialdo Martins da Silveira Jr.[3] and Silvia Maria Mathes Faustino[3]

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ABSTRACT

During the various hydrological periods in 2011, we studied the phytoplankton along an 87-km stretch of the Araguari and Falsino rivers, which are located in the eastern Brazilian Amazon, in the state of Amapá, Brazil, the most ecologically preserved state in the country. In the study area, the aquatic ecosystem is under pressure from human activities such as, mining, hydroelectric power generation and urbanization, which contrast with the surrounding areas that are designated for biodiversity conservation. The aim of this study was to characterize the composition, frequency and richness of algae species and also to identify spatial-temporal patterns of taxa distribution. During the study period, we identified 185 taxa (136 species in 49 genera). The division Chlorophyta (class: Zygnematophyceae) presented the greatest number of taxa, whereas the division Rhodophyta accounted for only 1% of the taxa recorded. Most of the species identified (69%) were classified as sporadic in occurrence. The few taxa that were classified as common belonged mainly to the group Bacillariophyta. Species richness was greatest richness in the lentic stretches (in a reservoir) and in November (during the dry season). Of the 185 taxa identified, 174 are new records for the state of Amapá.

Key words: algae, Amapá, floristic survey, reservoir, river

Introduction

Phytoplankton is composed of microscopic organisms, also known as algae, which remain at the surface of water bodies. These organisms provide essential environmental services such as oxygen production for the aquatic environment (Wehr & Descy 1998) and for the atmosphere, from which they also sequester carbon dioxide (Ohse *et al.* 2009). In addition, these organisms form the base of the food chain of aquatic ecosystems and supply much of the carbon dioxide that is necessary to fishes, which are a primary source of protein for human populations (Araújo-Lima *et al.* 1986).

The Brazilian continental waters are rich in phytoplankton and present considerable phytoplankton biodiversity, with approximately 25% of the species in the world (Agostinho *et al.* 2005). Knowledge of the biodiversity of these algae is, however, quite heterogeneous regarding geographic region, taxonomic group (Bicudo & Menezes 2010) and type of aquatic ecosystem (Soares *et al.* 2007).

In Brazil, data related to algae is generated primarily in the southern and southeastern regions of the country, followed by the northeastern region, where substantial knowledge of these organisms has been gathered, despite the scarcity of hydrological resources in the region. Very little is known regarding the biodiversity of algae in the central-west and northern regions of Brazil, where the largest watershed in the world is located (Bicudo & Menezes 2010). Specifically in the state of Amapá, knowledge of phytoplankton is even scarcer, only two studies having been conducted to date (Förster 1964; Souza & Melo 2011).

Certain taxonomic groups of phytoplankton have been more widely studied than others. This has been the case for the Amazon region, where few studies have addressed the phytoplankton community as a whole (Huszar & Reynolds 1997; Ibañez 1998; Melo & Huszar 2000; Melo *et al.* 2005a; Paiva *et al.* 2006; Aprile & Mera 2007; Monteiro *et al.* 2009; Pereira *et al.* 2010; Almeida & Melo 2011). Most studies conducted in the region have examined specific taxonomic groups, such as desmids (Grönblad 1945; Förster 1963, 1964, 1969, 1974; Scott *et al.* 1965; Thomasson 1971; Sophia & Huszar 1996; Lopes & Bicudo 2003; Melo *et al.* 2005b; Souza *et al.* 2007; Melo & Souza 2009; Melo *et al.* 2009; Souza & Melo 2011) and diatoms (Diaz-Castro *et al.* 2003; Ferrari *et al.* 2007; Pereira *et al.* 2012; Raupp *et al.* 2009;

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[2] Universidade Federal do Amapá, Programa de Pós-Graduação em Biodiversidade Tropical, Macapá, AP, Brazil
[3] Universidade Federal do Amapá, Programa de Pós-Graduação em Ciências da Saúde, Macapá, AP, Brazil
[4] Author for correspondence: elanedsc@yahoo.com.br

Sala *et al*. 2002; Tudesque *et al*. 2012; Wetzel *et al*. 2012).

Most studies of algae in Brazil have involved small aquatic ecosystems, such as lakes, lagoons and reservoirs (Silva *et al.* 2001; Bozelli & Huszar 2003). The phytoplankton biodiversity in the rivers of Brazil is still poorly studied, despite the extensive river system in the country (Soares *et al*. 2007). This is attributable, in part, to the high cost and complex logistics of conducting research on rivers in comparison with those of studies carried out in discrete environments (small lakes and reservoirs), features that Bozelli & Huszar (2003) referred to as "methodological difficulties".

In this context, it is necessary to increase research efforts regarding phytoplankton biodiversity, especially in the Amazon, where there are plans for the construction of hydroelectric plants, which significantly alter the flow of rivers and, consequently, the dynamics of aquatic organisms (Zeng *et al.* 2006). In addition, this is one the least served regions of Brazil regarding sewage treatment, as noted by Cunha *et al.* (2004; 2005) and Agostinho *et al.* (2005). According to those authors, the construction of dams in the region will compound the problems caused by inadequate sewage treatment. Taken separately or together, these two factors present a major threat to aquatic biodiversity, potentially resulting in local extinctions and alterations within communities.

In the region of our study site, the aquatic ecosystem is facing pressures caused by human activities such as mining, construction of medium-sized hydroelectric plants, and urbanization, activities that put the site in contrast with the surrounding areas, which are dedicated to biodiversity conservation. In addition to a recently constructed hydroelectric plant, another two hydroelectric plants are currently under construction on the same stretch of river (Cunha *et al.* 2011; 2013). In this scenario, the objective of the present study was to record the biodiversity within this ecosystem prior to its further modification. By characterizing the composition, frequency and richness of the phytoplankton communities in two Amazonian rivers (one in a conservation area and one already under the influence of hydroelectric plants), identifying spatial and temporal patterns in the distribution of taxa, we hope to improve the knowledge of phytoplankton biodiversity in such rivers.

Material and methods

The state of Amapá is located in the extreme north of Brazil, in the eastern portion of the Amazon basin, and 62% of its territory is set aside through the establishment of constructs such as conservation units, environmentally protected areas, legal reserves, remaining territories of *quilombos* (Brazilian settlements founded by escaped or freed slaves) and lands reserved for use by indigenous tribes, making it the most ecologically preserved state in the country (Brito, 2008).

The Araguari and Falsino rivers are part of the watershed of the Araguari river, the largest watershed exclusive to the state of Amapá. These are considered "clear-water" rivers, because of the small quantity of suspended particles (Junk *et al.* 2012), are acidic (like the majority of Amazonian rivers) and contain 6-8 mg/L of dissolved oxygen (Bárbara *et al.* 2010; Cunha *et al*. 2011). According to the Brazilian National Environmental Council, these rivers are categorized as class II, meaning that their water is potable (after conventional treatment); their aquatic species are protected; and they are open to recreation, irrigation, aquiculture and fishing (Brasil, 2005). These rivers are turbulent, because the declivity is 0.50% at the beginning of the stretch (site F1), resulting in high flow rates, which decrease near the Coaracy Nunes Hydroelectric Plant (CNHP) reservoir, where the declivity drops to 0.35%, and are considered to have a high self-purification capacity (Bárbara *et al.* 2010; Cunha *et al.* 2011; 2013).

The stretch of river selected for this study is 87 km long, beginning at the Amapá National Forest, on the Falsino river, and ending at the CNHP reservoir on the Araguari river (Fig. 1). This stretch is strategically important regarding land use, which varies from conservation units to human activities that are common in the Amazon basin, such as mining, including pebble extraction (Bárbara *et al.* 2010); urbanization (small- to medium-sized cities); and, mainly, the generation of hydroelectric energy (Cunha *et al.* 2011).

We conducted phytoplankton surveys at 14 sampling sites arranged as indicated in Tab. 1. These sites—designated F1 (within a conservation unit on the Falsino river); P1-P4 and P6-P9 (on lands used for various purposes along both rivers); and R1-R5 (on the CNHP reservoir, Araguari river)—were chosen in order to continue the historic water quality series developed by Bárbara *et al.* (2010) and Cunha *et al.* (2010) on the Araguari and Falsino rivers. Our surveys were conducted in February, May, August and November of 2011, corresponding to the following hydrological periods, respectively: dry-wet seasonal transition, wet season, wet-dry seasonal transition and dry season.

We obtained phytoplankton samples using a 20 μm mesh plankton net. A total of 56 samples were collected. The samples were subsequently fixed in Transeau's solution (Bicudo & Menezes 2006). The taxa were identified under standard light microscopy with the aid of specialized bibliography, which included but was not limited to Grönblad (1945), Förster (1963; 1964), Komárek & Anagnostidis (1999; 2005) and Bicudo & Menezes (2006). Whenever possible, specimens were identified down to the species level.

We used the system devised by Hoek *et al.* (1995) to arrange the taxa in divisions and classes, except for the division Heterokontophyta, which was separated into Bacillariophyta and Chrysophyta. This procedure was adopted to facilitate the comparison with similar studies, because most still make use of this nomenclature. The classification of diatoms followed Medlin & Kaczmarska (2004).

The frequency for each taxon (expressed as a percentage) was calculated with the following formula:

$$(\textit{number of sample sites} \times 100)/56$$

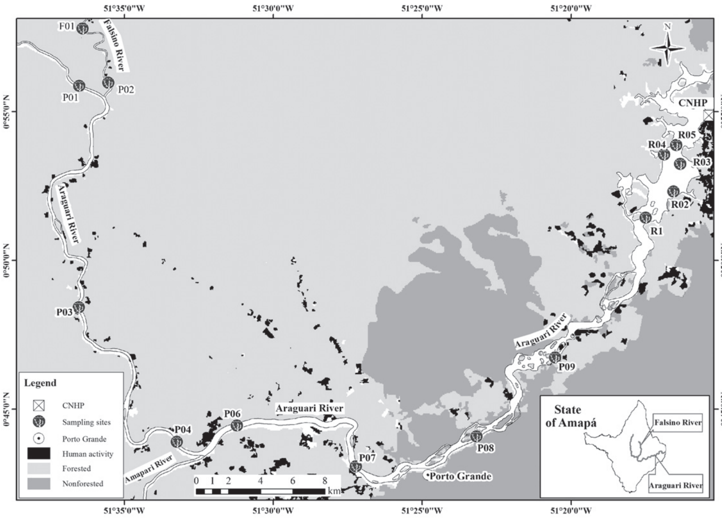

Figure 1. Map of the study site. Sampling sites on the Araguari and Falsino rivers.

Table 1. Description of the sampling sites on the Araguari and Falsino rivers.

Site	Location, characteristics and land use	Geographic coordinates	
F1	(F) Conservation unit, Amapá National Forest	0°57'37.00"N	51°36'22.00"W
P1	(A) Conservation unit, Amapá National Forest	0°55'47.70"N	51°36'33.48"W
P2	(F) Conservation unit, Amapá National Forest	0°55'54.48"N	51°35'37.20"W
P3	(A) Conservation unit, Amapá State Forest	0°48'24.00"N	51°36'37.80"W
P4	(A) Upstream of the confluence with the Amapari river	0°43'51.96"N	51°33'21.54"W
P6	(A) Downstream of the confluence with the Amapari river; mining	0°44'12.18"N	51°31'12.48"W
P7	(A) Municipality of Porto Grande; urbanization, mining, extraction of pebbles and ornamental stones	0°43'03.70"N	51°27'15.40"W
P8	(A) Downstream of the municipality of Porto Grande; mining	0°44'02.88"N	51°23'07.50"W
P9	(A) Downstream of waterfalls, river-reservoir transition	0°46'47.40"N	51°20'30.96"W
R1	(A) Reservoir (Coaracy Nunes Hydroelectric Plant)	0°51'11.88"N	51°17'22.92"W
R2	(A) Reservoir (Coaracy Nunes Hydroelectric Plant)	0°52'17.46"N	51°16'35.34"W
R3	(A) Reservoir (Coaracy Nunes Hydroelectric Plant)	0°53'13.20"N	51°16'21.78"W
R4	(A) Reservoir (Coaracy Nunes Hydroelectric Plant)	0°53'36.72"N	51°17'00.60"W
R5	(A) Reservoir (Coaracy Nunes Hydroelectric Plant)	0°53'53.16"N	51°16'35.94"W

(F) – Falsino river; (A) – Araguari river.

where 56 is the total number of samples in the temporal and spatial axes. Taxa were then divided into the following frequency classes, adapted from Mateucci & Colma (1982): quite common (> 70%); relatively common (70-40%); relatively uncommon (40-10%); and sporadic (≤ 10%).

To determine whether phytoplankton composition was similar among sampling sites, we conducted a cluster analysis with Ward's method and determined Euclidean distances using the software R-Project 2.14 (R Development Core Team 2012).

To verify new records for the state of Amapá, we reviewed studies on continental microalgae carried out in the state (Förster 1964; Souza & Melo 2011).

The samples were deposited in the liquid collection of the herbarium of the Institute for Scientific and Technological Research in the State of Amapá (code, HAMAB) under the accession numbers 0000001 through 0000056.

Results

We recorded 185 taxa (Tab. 2)—49 identified down to the genus level and 136 identified down to the species level—within five divisions and ten classes. The divisions that were the most well-represented were Chlorophyta (with 71.9% of the taxa), Cyanophyta (with 14.6%) and Bacillariophyta (with 10.9%), Chrysophyta and Rhodophyta accounting for only 1.6% and 1.0%, respectively (Fig. 2).

Table 2. Complete list of taxa with their respective frequency classes and site of occurrence (n of samples = 56).

DIVISION Class Genus and species	FC	Sampling sites													
		F1	P1	P2	P3	P4	P6	P7	P8	P9	R1	R2	R3	R4	R5
CYANOPHYTA															
Cyanophyceae															
Aphanocapsa delicatissima West & West*	S									x		x			
Aphanocapsa sp.*	S							x	x					x	
Aphanothece sp.*	S	x	x		x								x		
Aphanothece stagnina (Sprengel) Braun*	S		x												
Bacularia gracilis Komárek*	RU	x		x			x	x			x	x			
Chamaesiphon sp.*	RU	x	x			x	x	x	x	x	x	x	x		x
Chroococcus dispersus (Keissler) Lemmermann*	S			x											
Cyanosarcina sp.*	S												x	x	x
Leptolyngbya sp.*	QC	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lyngbya sp.*	RU	x	x	x	x		x	x		x		x		x	
Nostoc sp.*	S											x			
Oscillatoria limosa Agardh ex Gomont*	S														x
Oscillatoria princeps Vaucher ex Gomont*	S							x			x			x	x
Phormidium autumnale (Agardh) Trevisan ex Gomont*	S														x
Phormidium granulatum (Gardner) Anagnostidis*	S											x			
Phormidium retzii (Agardh) Gomont ex Gomont*	S										x				x
Phormidium sp.*	S			x								x			
Phormidium stagninum (Kützing ex Gomont) Anagnostidis*	S								x						
Phormidium tergestinum (Gomont) Anagnostidis & Komárek*	S									x					
Planktothrix agardhii (Gomont) Anagnostidis & Komárek*	S	x													
Planktothrix isothrix (Skuja) Komárek & Komárková*	S						x								
Planktothrix sp.*	S						x			x					
Pseudanabaena galeata Böcher*	S												x		
Pseudanabaena mucicola (Naumann & Huber-Pestalozzi) Schwabe*	S	x		x				x							
Pseudanabaena sp.*	S											x		x	x
Scytonema sp.*	RU	x	x	x			x		x			x			
Stigonema sp.*	RU	x	x	x			x	x	x	x					
RODOPHYTA															
Florideophyceae															
Balliopsis prieurii (Kützing) Saunders & Necchi-Júnior*	S	x		x	x		x								
Batrachospermum sp.*	RC	x	x	x	x	x	x	x	x	x	x	x	x		x
BACILLARIOPHYTA**															
Bacillariophyceae															
Actinella mirabilis Grunow*	RU	x	x	x	x	x	x	x	x		x				x
Amphora delphinea Cleve*	RU	x	x	x	x	x		x							
Asterionella formosa Hassall*	RU	x		x			x	x	x	x	x	x		x	x
Eunotia pseudoserra De Oliveira & Steinitz-Kannan*	S						x								
Eunotia subrobusta Hustedt*	S	x		x	x		x								

Continues

Table 2. Continuation.

DIVISION / Class / Genus and species	FC	Sampling sites													
		F1	P1	P2	P3	P4	P6	P7	P8	P9	R1	R2	R3	R4	R5
Eunotia yanomami Metzeltin & Lange-Bertalot*	RC	x	x	x	x	x		x	x	x	x	x	x	x	x
Fragilaria sp.*	RC	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Gomphonema neonasutum Lange-Bertalot & Reichardt*	S						x	x					x		
Pinnularia sp.*	RU	x	x	x	x	x		x	x			x	x	x	x
Placoneis sp.*	S			x			x			x			x		x
Platessa sp.*	S			x											
Stauroneis sp.*	RU			x	x	x		x			x	x			x
Surirella grunowii sensu Kulikovskiy, Lange-Bertalot & Witkowski*	RC	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Surirella guatimalensis Ehrenberg*	RU				x				x	x	x		x		x
Surirella linearis Smith*	QC	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Synedra sp.*	S					x							x		
Tabellaria sp.*	RC	x		x	x	x	x	x	x	x	x	x	x	x	x
Coscinodiscophyceae															
Aulacoseira granulata (Ehrenberg) Simonsen*	S										x	x		x	x
Aulacoseira sp.*	RU	x	x	x				x					x	x	x
Mediophyceae															
Terpsinoe musica Ehrenberg*	S									x	x				x
CHRYSOPHYTA**															
Chrysophyceae															
Dinobryon sp.*	RU			x							x	x	x	x	x
Rhipidodendron huxleyi Kent*	QC	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Synura uvella Ehrenberg*	RU	x	x	x	x	x		x	x	x	x	x	x	x	x
CHLOROPHYTA															
Chlorophyceae															
Ankistrodesmus densus Korshikov*	S									x	x	x			x
Ankistrodesmus fusiformis Corda*	S										x				
Asterococcus limneticus Smith*	S													x	
Botryosphaera sp.*	S											x	x		
Coelastrum cambricum Archer*	RU						x		x	x			x	x	x
Coelastrum reticulatum (Dangeard) Senn*	S	x								x	x				
Desmodesmus communis (Hegewald) Hegewald*	S										x			x	x
Desmodesmus dispar (Brébisson) Hegewald*	S										x				
Dictyosphaerium pulchellum Wood*	RU		x		x	x		x		x	x	x	x	x	x
Elakatothrix linearis Pascher*	S														x
Eudorina elegans Ehrenberg*	S									x		x	x		
Eudorina sp.*	RU		x		x	x		x	x	x	x	x	x	x	x
Gloeocystis sp.*	S											x			
Golenkinia radiata Chodat*	RU					x	x	x	x		x	x	x	x	x
Hydrodictyon reticulatum (Linnaeus) Bory de Saint-Vincent*	RC	x	x	x	x	x	x	x	x	x	x	x	x		
Kirchneriella sp.*	RU	x									x	x	x	x	x

Continues

Table 2. Continuation.

DIVISION Class Genus and species	FC	Sampling sites													
		F1	P1	P2	P3	P4	P6	P7	P8	P9	R1	R2	R3	R4	R5
Micractinium sp.*	S										x				
Microspora sp.*	RU	x	x				x		x	x		x			
Nephrocytium sp.*	S													x	x
Oedogonium sp.*	RU	x	x	x		x						x			
Oocystis sp.*	S												x	x	
Pandorina sp.*	S										x		x		x
Pediastrum duplex Meyen*	RU											x	x	x	x
Planktosphaeria gelatinosa Smith*	S														x
Radiococcus sp.*	S										x				
Scenedesmus acuminatus (Lagerheim) Chodat*	S										x	x	x	x	x
Scenedesmus sp.*	S							x							
Sphaerocystis schroeteri Chodat*	S											x	x		x
Volvox sp.*	S									x					
Cladophorophyceae															
Cladophora sp.*	S			x											
Rhizoclonium sp.*	S				x						x	x			
Ulvophyceae															
Binuclearia sp.*	S									x				x	x
Zygnematophyceae															
Actinotaenium wollei (West & West) Teiling*	RU		x		x	x	x			x	x	x	x	x	x
Bambusina sp.*	RU						x		x		x	x	x	x	x
Closterium dianae Ehrenberg ex Ralfs*	S				x		x						x		
Closterium ehrenbergii Meneghini ex Ralfs*	RU		x		x	x			x		x	x	x		x
Closterium incurvum Brébisson*	S	x	x		x						x		x		
Closterium kuetzingii Brébisson*	RU		x			x		x			x	x	x	x	x
Closterium lanceolatum Kützing ex Ralfs*	S											x			
Closterium lineatum Ehrenberg ex Ralfs*	S													x	
Closterium moniliferum (Bory) Ehrenberg ex Ralfs*	RU	x	x	x			x	x	x		x	x	x	x	x
Closterium porrectum Nordstedt*	S												x		
Closterium ralfsii Brébisson ex Ralfs*	S							x					x		
Closterium rostratum Ehrenberg ex Ralfs*	RU		x		x	x	x	x	x	x	x				x
Closterium setaceum Ehrenberg ex Ralfs*	RU										x	x	x	x	x
Closterium striolatum Ehrenberg ex Ralfs*	S			x	x			x							
Closterium tortum Griffiths*	S		x			x									
Closterium tumidum Johnson*	S							x							
Cosmarium comissurale Brébisson ex Ralfs*	S					x							x		
Cosmarium contractum Kirchner*	S											x		x	x
Cosmarium lagoense (Nordstedt) Nordstedt*	S													x	x
Cosmarium lundelli Delponte*	S													x	
Cosmarium margaritatum (Lundell) Roy & Bisset*	S											x			

Continues

Table 2. Continuation.

DIVISION Class Genus and species	FC	Sampling sites													
		F1	P1	P2	P3	P4	P6	P7	P8	P9	R1	R2	R3	R4	R5
Cosmarium pachydermum Lundell*	S													x	
Cosmarium subspeciosum Nordstedt*	S		x	x			x							x	x
Cylindrocystis sp.*	S							x		x	x				
Desmidium aptogonum Brébisson ex Kützing*	S						x			x				x	
Desmidium baileyi (Ralfs) Nordstedt*	S													x	x
Desmidium graciliceps (Nordstedt) Lagerheim*	S												x		
Desmidium grevillii (Ralfs) De Bary*	RU											x	x	x	x
Desmidium laticeps Nordstedt	S													x	
Desmidium quadratum Nordstedt*	RU						x	x	x		x	x	x	x	x
Desmidium swartzii (Agardh) Agardh ex Ralfs*	S													x	
Euastrum evolutum (Nordstedt) West & West*	S										x		x		
Euastrum sinuosum Lenormand ex Archer*	S												x		
Euastrum spinulosum Delponte*	S													x	x
Euastrum subhypochondrum Fritsch & Rich*	S														x
Gonatozygon pilosum Wolle*	RU								x	x	x	x		x	x
Gonatozygon sp.*	RU	x		x		x		x	x	x	x	x	x	x	x
Haplozyga sp.*	S													x	x
Hyalotheca dissiliens Brébisson ex Ralfs*	S								x				x	x	
Hyalotheca mucosa (Mertens) Ehrenberg ex Ralfs*	RU				x		x	x	x	x	x	x	x	x	x
Mesotaenium sp.*	S											x			
Micrasterias alata Wallich*	S													x	x
Micrasterias borgei Krieger*	S													x	
Micrasterias furcata Agardh ex Ralfs*	S													x	x
Micrasterias laticeps Nordstedt*	RU		x	x	x	x		x	x	x	x	x	x	x	x
Micrasterias pinnatifida (Kützing) ex Ralfs*	S														x
Micrasterias radians Turner*	S									x				x	
Micrasterias radiosa Ralfs*	S						x								
Micrasterias rotata (Greville) Ralfs*	S						x			x		x	x		
Micrasterias thomasiana Archer*	S									x		x			x
Micrasterias torreyi Bailey ex Ralfs*	S												x	x	
Micrasterias truncata (Corda) Brébisson ex Ralfs*	S											x			
Mougeotia sp.*	RC	x	x			x	x	x	x	x	x	x	x	x	x
Onychonema laeve Nordstedt*	S											x		x	x
Pleurotaenium coronatum (Brébisson ex Ralfs)*	S										x				x
Pleurotaenium ehrenbergii (Brébisson ex Ralfs) Delponte*	S							x	x						
Pleurotaenium subcoronulatum (Turner) West & West*	S											x			
Pleurotaenium subundulatum Borge*	S													x	
Pleurotaenium trabecula (Ehrenberg) ex Nägeli*	S								x					x	
Sirogonium sp.*	S								x						
Spirogyra sp.*	RU	x	x	x	x				x		x	x	x	x	x

Continues

Table 2. Continuation.

DIVISION Class Genus and species	FC	Sampling sites													
		F1	P1	P2	P3	P4	P6	P7	P8	P9	R1	R2	R3	R4	R5
Spirotaenia sp.*	S							x							
Spondylosium moniliforme Lundell*	S											x		x	
Spondylosium panduriforme (Heimerl) Teiling*	S													x	
Spondylosium planum (Wolle) West & West*	S											x	x		x
Spondylosium pulchrum (Bailey) Archer*	S													x	x
Staurastrum asteroideum West & West*	S				x	x								x	
Staurastrum boergesenii Raciborski	S													x	
Staurastrum coarctatum Brébisson*	S											x		x	x
Staurastrum columbetoides West & West*	S													x	
Staurastrum grallatorium Nordstedt	RU											x		x	x
Staurastrum hagmannii Grönblad*	S													x	x
Staurastrum leptacanthum Nordstedt	RU											x	x	x	x
Staurastrum leptocladum Nordstedt*	RU											x	x	x	x
Staurastrum manfeldtii Delponte*	RU													x	x
Staurastrum margaritaceum (Ehrenberg) Ralfs*	RU		x		x	x						x		x	x
Staurastrum minnesotense Wolle*	S												x		
Staurastrum novae-caesareae Wolle	S													x	x
Staurastrum ophiura Lundell*	S													x	
Staurastrum oxyacanthum Archer*	S													x	
Staurastrum penicilliferum Grönblad*	S													x	
Staurastrum quadrangulare (Brébisson) Ralfs	S											x			
Staurastrum rotula Nordstedt	RU											x		x	x
Staurastrum setigerum Cleve	RU	x	x	x	x	x	x	x		x	x	x	x	x	x
Staurastrum subindentatum West & West*	S													x	
Staurastrum trifidum Nordstedt	S											x		x	x
Staurastrum vestitum Ralfs*	S												x	x	x
Staurastrum wolleanum Butler*	S											x		x	x
Staurodesmus bulnheimii (Raciborski) Round & Brook*	S														x
Staurodesmus connatus (Lundell) Thomasson*	S											x		x	
Staurodesmus convergens (Ehrenberg ex Ralfs) Teiling	S											x	x		x
Staurodesmus cuspidatus (Brébisson) Teiling	S													x	
Staurodesmus leptodermus (Lundell) Thomasson*	S										x				
Staurodesmus lobatus (Börgesen) Bourrelly*	S													x	x
Staurodesmus mamillatus (Nordstedt) Teiling*	RU											x	x	x	x
Staurodesmus selenaeus (Grönblad) Teiling*	S													x	
Triploceras gracile Bailey*	S													x	x
Xanthidium antilopaeum (Brébisson) Kützing*	RU												x	x	x
Xanthidium regulare Nordstedt*	S												x	x	
Zygnema sp.*	RU	x		x		x		x			x	x	x		x

FC – frequency class; S – sporadic; RU – relatively uncommon; RC – relatively common; QC – quite common.
*New records; **Heterokontophyta, according to Hoek et al. (1995).

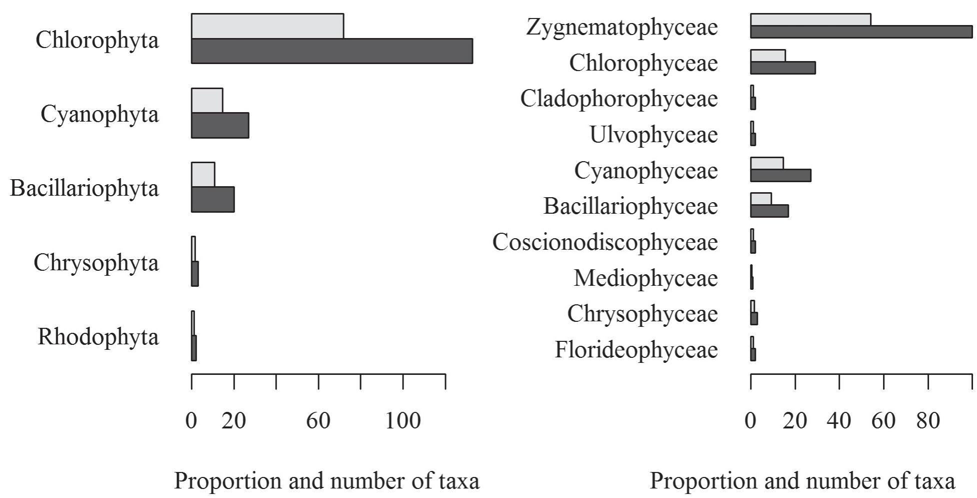

Figure 2. Distribution of taxa by division (left side) and class (right side), showing frequencies (light bars) and absolute values (grey bars).

As shown in Fig. 2, the division Chlorophyta was represented by the classes Zygnematophyceae (54.05%), Chlorophyceae (15.68%), Cladophorophyceae (1.08%) and Ulvophyceae (1.08%); Cyanophyta was represented by the class Cyanophyceae (14.59%); Bacillariophyta was represented by the classes Bacillariophyceae (9.19%), Coscinodiscophyceae (1.08%) and Mediophyceae (0.54%); Chrysophyta was represented by the class Chrysophyceae (1.62%); and Rhodophyta was represented by the class Florideophyceae (1.08%).

The class Zygnematophyceae had the most taxa (n = 100), followed by Chlorophyceae (n = 29). Those two classes collectively accounted for 70% of the taxa, which explains the high representation of the division Chlorophyta. The group Cladophorophyceae had the smallest number of representatives (n=2).

The most common taxa (those categorized as quite common or relatively common) in the Araguari and Falsino rivers were *Surirella linearis* (89.0%), *Leptolyngbya* sp. (84.0%), *Rhipidodendron huxleyi* (71.0%), *Fragilaria* sp. (68.0%), *Eunotia yanomami* (61.0%), *Batrachospermum* sp. (59.0%), *Hydrodictyon reticulatum* (55.0%), *Surirella grunowii* (54.0%), *Mougeotia* sp. (45.0%), and *Tabellaria* sp. (45.0%). Five of the ten most common species belonged the group Bacillariophyta.

The majority of taxa showed a low frequency: 69.0% were categorized as sporadic and 25.0% were categorized as relatively uncommon. Only 4.0% and 2.0% of the taxa were categorized as relatively common and quite common, respectively (Fig. 3).

Fig. 4 shows the spatial distribution of taxa. The sites with the highest richness were R4 (n = 96), R5 (n = 92), R2 (n = 77), R3 (n = 69), and R1 (n = 57). Those same sites (R2-R5) were grouped together in the cluster analysis (Fig. 5). The site with the smallest number of taxa was P4, with only 33 taxa. As can be seen in Fig. 6, species richness was highest (n = 132) during the dry season (November) and lowest (n = 73) during the dry-wet seasonal transition (February).

As previously mentioned, there have been only two studies on continental microalgae conducted in the state of Amapá (Förster 1964; Souza & Melo 2011). Our study had 11 taxa in common with those two works (Tab. 3). Therefore, of the 185 taxa identified in the present study, 174 represent new records for the state (Tab. 2).

Discussion

The division Chlorophyta had the highest number of taxa, which occurred mostly in the CNHP reservoir. This environment provided conditions that were more favorable for the development of the phytoplankton than were those elsewhere on the river, which is quite turbulent, a condition to which few species can adapt. Other rivers with dams display this same pattern: the Contas river, in the state of Bahia (Fuentes *et al*. 2010); the Corumbá river, in the state of Goiás (Silva *et al*. 2001); and the Paranapanema river, in the southeast of Brazil (Nogueira *et al.* 2010).

The class Zygnematophyceae had the largest number of taxa. That is probably attributable the characteristics of the two studied rivers. According to Coesel (1982), oligotrophic waters, with the presence of macrophytes and low electric conductivity, have a high richness of desmids. Bárbara *et al*. (2010) and Cunha *et al*. (2011) both classified the Araguari and Falsino rivers as oligotrophic and found that the CNHP reservoir, where desmids were more numerous, had aquatic macrophytes. In the Amazon basin, there is considerable desmid diversity, making it one of the best known groups in the region (Grönblad 1945; Förster 1963, 1964, 1969, 1974; Scott *et al*. 1965; Thomasson 1971;

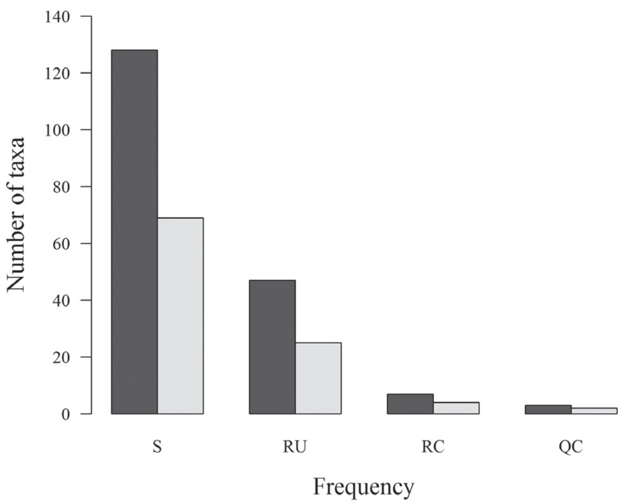

Figure 3. Distribution of taxa by frequency, showing frequencies (light bars) and absolute values (grey bars).
S – sporadic; RU – relatively uncommon; RC – relatively common; QC – quite common.

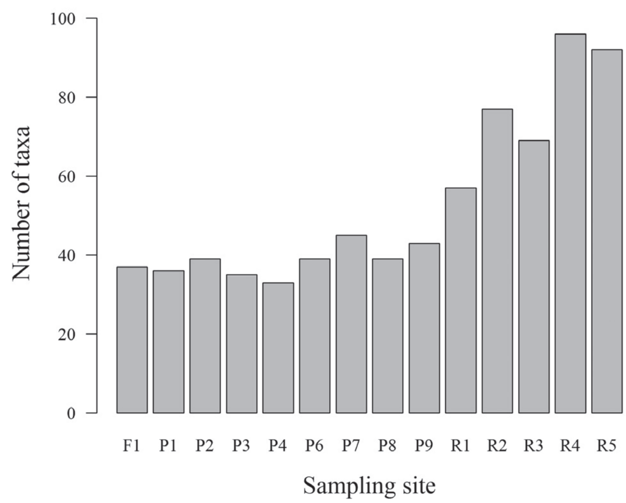

Figure 4. Distribution of taxa among the sampling sites.

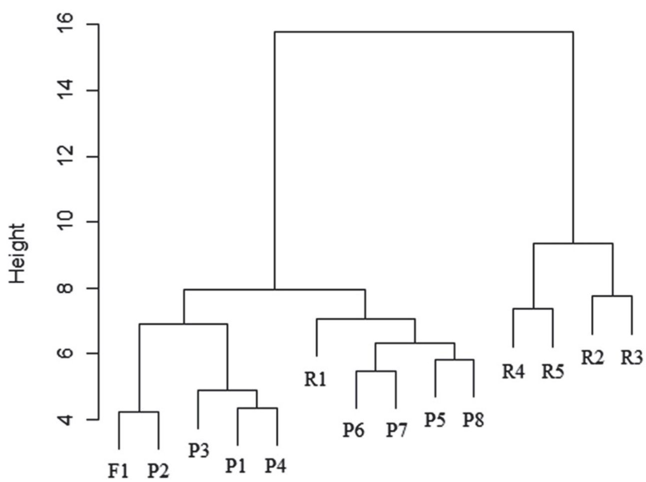

Figure 5. Cluster analysis*:* groupings according to the similarity of species composition among the sampling sites.

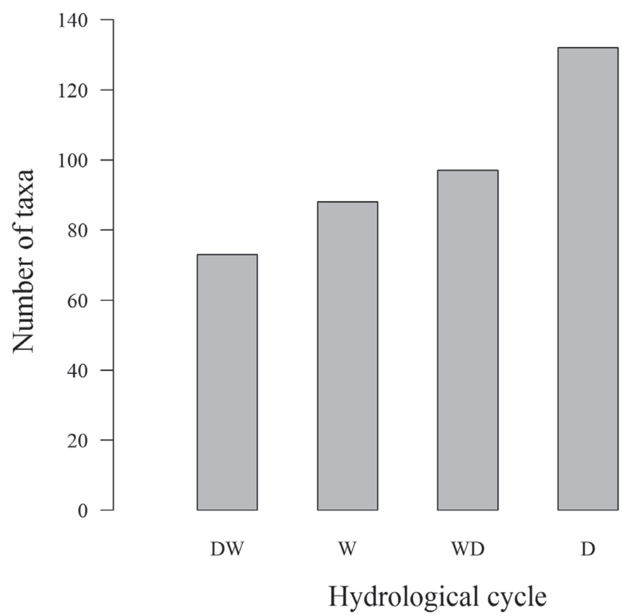

Figure 6. Distribution of taxa by hydrological period.
DW – dry-wet seasonal transition; W – wet season; WD – wet-dry seasonal transition; and D – dry season.

Sophia & Huszar 1996; Lopes & Bicudo 2003; Melo & Souza 2009; Souza & Melo 2011).

The majority of the most common taxa belonged to the division Bacillariophyta. This result was expected, because diatoms are typical of predominantly lotic environments (Soares *et al*. 2007). These organisms did not exhibit the highest richness, but they occurred in almost all samples. In a study conducted on the Arataï river in French Guiana, which shares a border with the state of Amapá, Tudesque *et al.* (2012) reported that *Surirella* sp., the most common genus in our study, is adapted to the turbulence of rivers and possesses high mobility. Furthermore, these authors

Table 3. Previous studies of continental microalgae in the state of Amapá: taxa in common with the present study.

Reference	Taxa in common with the present study	
Sampling site	Number	Species
Förster (1963) Oiapoque river	1	*Desmidium laticeps*
Souza & Melo (2011) Novo Lake	10	*Staurastrum boergesenii*; *Staurastrum grallatorium*; *Staurastrum leptacanthum*; *Staurastrum novae-caesareae*; *Staurastrum quadrangulare*; *Staurastrum rotula*; *Staurastrum setigerum*; *Staurastrum trifidum*; *Staurodesmus convergens*; and *Staurodesmus cuspidatus*

observed the diatoms *Eunotia* sp., *Fragilaria* sp. and *Surirella* sp. in high frequency, similar to our findings on the Araguari and Falsino rivers. Diatoms have also been reported to be the most common group on other Amazonian rivers such as the Guamá and Caeté, in the state of Pará (Monteiro *et al*. 2009; Pereira *et al*. 2010).

The high frequency of diatoms in the present study might be explained by their ability to adapt to conditions of high turbulence (Reynolds *et al*.1994), a typical characteristic of rivers (Press *et al*. 2003). For the stretch of river studied Cunha *et al*. (2010; 2011) reported the mean water velocity to be 0.57-0.92 m/s in the lotic stretch (upstream) and 0.04 m/s in the lentic stretch (CNHP reservoir). Branco *et al*. (1986) categorized the water velocity as: quite rapid (> 0.5 m/s), or moderate-to-slow (≤ 0.5 m/s). Therefore, the studied stretch of river can be considered mostly turbulent because of its high water velocity, which tends to naturally decrease toward the dam. In the CNHP reservoir, however, the speed is not uniform as in totally lentic environments, because its water retention time is only two to five days, and its characteristics therefore resemble those of a river more than those of a lake (Bárbara *et al*. 2010; Cunha *et al*. 2013).

In the present study, most of the taxa were classified as sporadic, occurring in less than 10% of the samples. According to Townsed *et al*.(2008), this pattern is normal, because these species in general are naturally rare. In studies conducted on the Guamá and Paranaíba rivers (Monteiro *et al*. 2009; Oliveira *et al*. 2011), the majority of taxa were also classified as sporadic.

The spatial distribution of taxa was aggregate in the CNHP reservoir. The majority of these taxa are desmids, which present slow growth and require lentic environments for their development (Coesel, 1982). The dendrogram of the cluster analysis (Fig. 5) indicated one cluster associated with the reservoir sampling sites and two additional large clusters, one associated with the sites near the beginning of the stretch of river studied and another associated with sites intermediate between the two ends of the stretch. Considering the species composition, the locations of these clusters might be related to the declivity of the land at the sampling sites and, consequently, to the water velocity, the declivity being similar among sites within the same group. The sites at the beginning of the stretch (F1 and P1-P4) had high declivity, the remaining sites along the stretch (P6-P9 and R1) had intermediate declivity, and the sites at the reservoir had low declivity, resulting in low water velocity (Cunha *et al*. 2011), the last creating the most favorable conditions for the development and reproduction of algae (Coesel, 1982).

Because of the presence of a reservoir in the stretch of river studied, we expected more taxa of the division Cyanophyta, or that their distribution would be more restricted to the reservoir, because these organisms typically occur in lentic environments, with a long water retention time (Chorus & Bartram, 1999). However, the CNHP reservoir has a water retention time of two to five days; that is, all the water in the reservoir is renewed in a relatively short period of time, even when considering the complete hydrological cycle (Cunha *et al*. 2011). Much longer water retention times have been reported for the reservoirs of other hydroelectric plants in the Amazon basin (Tucci, 1998): 50, 107 and 578 days, respectively, at the Tucuruí, Samuel and Balbina reservoirs. This fast turnover prevents the occurrence of algal blooms, which, according to Chorus & Bartram (1999) do not usually occur in environments where the water retention time is shorter than five days. However, these characteristics might be altered with the construction of new reservoirs, and two additional hydroelectric plants are currently under construction on the stretch of river studied (Cunha *et al*. 2010; 2011; 2013). In fact, the water retention time might increase considerably. On rivers with dams, such as the Paraibuna river (in the state of Minas Gerais) and the Paranapaíba river (in the states of Goiás and Minas Gerais), Cyanophyta is the most well-represented division, in terms of the number of species (Soares *et al*. 2007; Oliveira *et al*. 2011). The increase in species richness seen during the dry season in the present study might be related to the physical characteristics of that season, such as greater solar radiation, higher temperatures and less precipitation, all of which favor the growth of algae (Kivrak 2006; Marques *et al*. 2012). In addition, water velocity tends to decrease during the dry season (Nogueira 2000; Zeng *et al*. 2006; Cunha *et al*. 2013).

The occurrence of a larger number of taxa during the dry season has also been reported for other Brazilian rivers, such as the Urubuí (Aprile & Mera 2007), Paraibuna and Pomba (Soares *et al*. 2007).

Reviewing the literature, we found only two studies of phytoplankton in the state of Amapá: Förster (1964), who studied desmids on the Oiapoque river and recorded five taxa; and Souza & Melo (2011), who conducted a survey of desmids in Amapá lake and recorded 35 taxa. Therefore, in the present study, we have identified the largest number of taxa recorded to date for the state of Amapá (185), of which 172 (93%) represent new records for the state.

Conclusion

We found that the species richness of the phytoplankton community of the Araguari and Falsino rivers was high in comparison with that reported in similar studies for the Amazon and for other regions of Brazil. This suggests that, in addition to the natural tendency toward an increase in species richness toward the tropics, the sampling effort was satisfactory, because we identified spatio-temporal variations within the microalgae community. We observed a large number of taxa belonging to the division Chlorophyta, class Zygnematophyceae, and most of the taxa identified were relatively rare. However, most of the taxa classified as common were diatoms. When we examined the spatio-temporal dynamics, we found that species richness was lowest at the sampling sites close to conservation units (sites with high declivity and high water velocity) and increased progressively at each site nearer to the CNHP reservoir (sites at which the declivity and water velocity were low). In addition, the number of taxa was highest in dry season. The 174 new records generated for the state of Amapá constitute a significant contribution to expanding the knowledge of aquatic biodiversity in the Brazilian Amazon.

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