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Macrophytes of the Capitão Poço river micro-basin, State of Pará, Eastern Amazon, Brazil: floristic composition and identification key for the species[1]

Lucimar Silva Carvalho[2,3], Witalo Cleidson Rodrigues Soares[2], Felipe Fajardo Villela Antolin Barberena[2] and Thaisa Pegoraro Comassetto[2]

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ABSTRACT – (Macrophytes of the Capitão Poço river micro-basin, State of Pará, Eastern Amazon, Brazil: floristic composition and identification key for the species). We aimed to characterize the floristic composition, detect the life forms, and provide an identification key for the macrophyte species of the Capitão Poço river micro-basin in the State of Pará, located in the Eastern Amazon. The collected specimens were identified and deposited in the HCP herbarium. We found 23 species distributed in 19 genera and 14 families of macrophytes. The families with the highest species richness were Cyperaceae (six spp.), Poaceae (three spp.), Onagraceae and Plantaginaceae (two spp. each). We present here the first record of *Dichanthelium aequivaginatum* from the Brazilian Amazon and the Northern region of Brazil. We suggest that floristic-taxonomic studies of macrophytes in the hydrographic basins of the northeastern region of Pará should be intensified in order to better understand the regional flora of this group.
Keywords: aquatic flora, Brazilian Amazon, checklist, new records, streams

RESUMO – (Macrófitas da microbacia do rio Capitão Poço, Amazônia Oriental, Brasil: composição florística e chave de identificação para as espécies). Nosso objetivo foi caracterizar a composição florística, detectar as formas de vida e fornecer uma chave de identificação para as espécies de macrófitas da microbacia do rio Capitão Poço, no Estado do Pará, localizada na Amazônia Oriental. Os espécimes coletados foram identificados e depositados no herbário HCP. Encontramos 23 espécies de macrófitas distribuídas em 19 gêneros e 14 famílias. As famílias com maior riqueza de espécies foram Cyperaceae (seis spp.), Poaceae (três spp.), Onagraceae e Plantaginaceae (duas spp. cada). Apresentamos aqui o primeiro registro de *Dichanthelium aequivaginatum* para a Amazônia Brasileira e região Norte do Brasil. Sugerimos que sejam intensificados os estudos florístico-taxonômicos de macrófitas nas bacias hidrográficas da região nordeste do Pará, a fim de conhecer melhor a flora regional deste grupo.
Palavras-chave: flora aquática, Amazônia Brasileira, inventário, novos registros, riachos

Introduction

Macrophytes are macroscopic photosynthetic organisms that can grow in permanently or seasonally humid environments (Cook *et al*. 1974, Couto *et al.* 2022). These organisms perform important ecosystem services, such as habitat structuring, nutrient cycling, supply of organic carbon and oxygen to the rhizosphere, reduction of water flow velocity, and stabilization of the filter bed (Cronin *et al.* 2006, Lahon & Sahariah 2022, Grzybowski *et al.* 2023). Macrophytes also influence the hydraulic conductivity, allow the transfer of nutrients at the soil-water interface and the accumulation of sediments in lakes with low slopes (Tundisi & Tundisi 2016), in addition to being phytoremediators, acting in the elimination of ammonia, phosphates and nitrates from water bodies (Esteves 2011). Apart from their ecological importance, macrophytes are used in animal and human food, fertilization, and production of medicines and cosmetics (Esteves 2011).

The Amazon basin is the largest freshwater basin on the planet and is predominantly located in Northern Brazil (Moura Júnior *et al.* 2015, Fares *et al.* 2021). Due to the environmental gradients present in the region, notably in the climate and limnological characteristics of the basins, the distribution, richness and composition of macrophyte species may vary across different water bodies (Moura Júnior *et al.* 2015). The disorderly growth of cities and increase in the global population have caused several environmental problems in aquatic ecosystems, mainly the irregular release of effluents and solid waste and deforestation (McDonald *et al.* 2020). The disturbances caused by urbanization profoundly modify the habitat, resulting in the disappearance of specialist species and consequent dominance of generalist ones (Ferreira *et al.* 2023).

The northeastern mesoregion of the State of Pará, in the Eastern Amazon, faces problems resulting from the lack sewage treatment and the consequences of agricultural activities such as itinerant family farming, which involves the slashing and burning

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2. Universidade Federal Rural da Amazônia, *Campus* Capitão Poço, Rua Professora Antônia Cunha de Oliveira s.n., Vila Nova, 68650-000 Capitão Poço, PA, Brazil
3. Corresponding author: lucimar.sicarvalho@gmail.com

of forest areas of different sizes (Barroso *et al.* 2015, Alves *et al.* 2018). The release of wastewater without prior treatment directly affects the basin of the Guamá River, which currently has 29% of its area altered (Rocha & Lima 2020). This basin is composed by eight sub-basins (Upper Guamá, Lower Guamá, Igarapé Apeú, Rio Bujaru, Middle Guamá west sector, Middle Guamá east sector, Igarapé Mãe do Rio, and Rio Sujo), covering 7% of the State of Pará and 19 municipalities (Kubota *et al.* 2020). Alterations are more noticeable in the Upper Guamá sub-basin, particularly in the Capitão Poço river micro-basin, where urban and agricultural activities result in the diffuse pollution of the *igarapés* and, very likely, the artificial eutrophication of water bodies (Alves *et al.* 2018). The Capitão Poço river micro-basin flows into the Upper Guamá sub-basin, which is widely used for animal husbandry, bathing, irrigation, fishing, and fish farming (Rodrigues 2018).

Land use change generally favors certain species and biological forms of macrophytes (Umetsu *et al.* 2018, Pereira *et al.* 2021, Bomfim *et al.* 2023). However, although a high richness of macrophyte species has been reported for the State of Pará (Moura Júnior *et al.* 2015, Fares *et al.* 2021), the diversity, life forms and diagnostic morphological characters of macrophyte species in most basins of this State, including those of Guamá, have not yet been comprehensively investigated. In this context, the objective of the present study was to characterize the floristic composition, detect the life forms, and provide an identification key for the macrophyte species of the Capitão Poço river micro-basin.

Material and methods

Study area - The study was carried out in the Capitão Poço river micro-basin (1°43'37.0"-1°46'57.5" S; 47°03'03.9"-47°05'41.2" W), which has approximately 112 km² and is restricted to the municipality of Capitão Poço, State of Pará, Brazil. The municipality is located in the northeastern mesoregion of Pará and the Guamá microregion, has an area of 2,899 km² and an average altitude of 73 meters above sea level (IBGE 2021). The climate in Capitão Poço is of the Am type (Alvares *et al.* 2013), with a markedly rainy (January to April) and a slightly drier (July to November) season, with an average annual precipitation of 2,449 mm and an average annual temperature of 26.9 °C (Pacheco & Bastos 2001, Santos 2013, Sauma Filho *et al.* 2020). The vegetation of the region is predominantly composed of secondary vegetation of Dense Ombrophilous Forest (IBGE 2023).

Data collection and analysis - Collections were carried out at eight sampling points in streams of first and second order (Strahler 1957) along the Capitão Poço river micro-basin, including stretches that cross the urban center of the municipality (points 2, 4 and 5, recognized as more urbanized) and others relatively far from it (points 1, 3, 6, 7 and 8, less urbanized) (figures 1 and 2), in order to cover locations with different levels of anthropization. Field expeditions took place in July, August, September, and November 2019 and from January to April 2020, in order to cover the different regional climatic seasons. Collection and processing of the botanical materials were carried out according to usual taxonomic procedures (Peixoto & Maia 2013) and the vouchers were deposited in the HCP herbarium (acronym according to Thiers 2023). The identification of macrophytes was carried out using relevant literature, such as Pott & Pott (2000), Souza & Lorenzi (2019), Flora e Funga do Brasil (2023), and especially floristic-taxonomic articles (Souza & Giulietti 2009, Barbosa 2012, Costa 2014, Duarte *et al.* 2015, Araújo 2017, Sousa *et al.* 2019, Fares *et al.* 2020a), in addition to consultations with taxonomists. The key to the identification of macrophyte species of the Capitão Poço river micro-basin was elaborated mainly based on the analysis of the collected specimens and, in addition, morphological information on the species available in Flora and Funga do Brasil (2023). The classification of biological forms was based on the concepts of Pedralli (2003) and Esteves (2011). We adopted the APG IV and PPG I classification systems for the taxa recorded (APG IV 2016, PPG I 2016).

Results

We found 23 species of macrophytes belonging to 19 genera and 14 families, including ferns, basal angiosperms, eudicots,

Figure 1. Capitão Poço river micro-basin in the State of Pará, Brazil, highlighting the location of the eight sampling points of macrophytes of the present study.

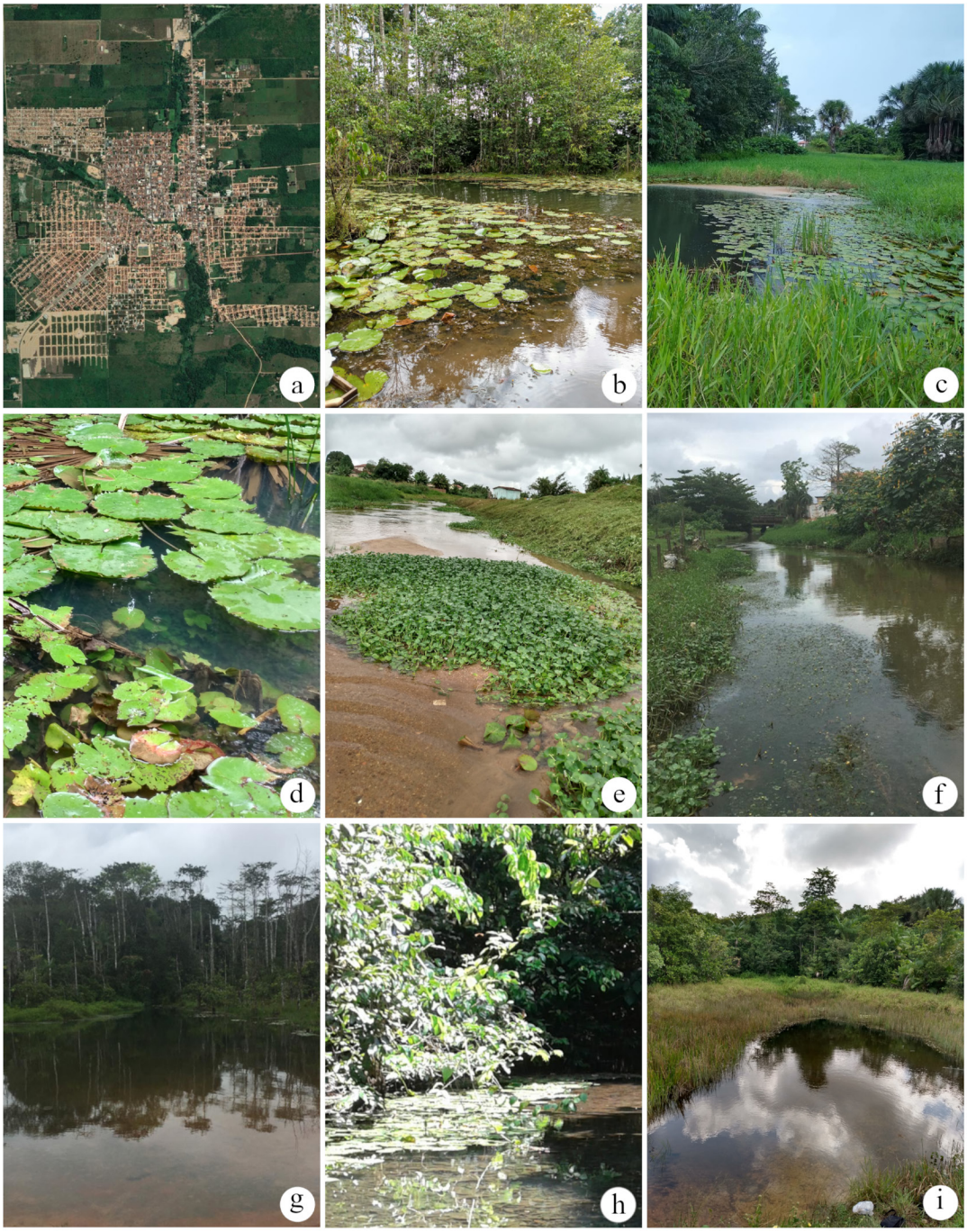

Figure 2. Satellite view of the urban center of the municipality of Capitão Poço, State of Pará, Eastern Amazon, Brazil (a). The eight sampling points of the present study, namely P1 (b), P2 (c), P3 (d), P4 (e), P5 (f), P6 (g), P7 (h), and P8 (i).

and monocots, in the Capitão Poço river micro-basin. The families with the highest species richness were Cyperaceae, with six species, Poaceae, with three species, and Onagraceae and Plantaginaceae, with two species each (figures 3 and 4, table 1). The genus *Cyperus* L. had three species and *Bacopa* Aubl. and *Ludwigia* L. had two species each. All other genera were represented by only one species each.

The species richness at the sampled points ranged from three (P1) to eight (P3) species. Two species (*Cabomba aquatic*a Aubl. and *Nymphaea rudgeana* G.Mey.) were found in all localities, while eight species were restricted to a single locality. Eighteen species occurred in areas further away from the urban center (P1, P3, P6, P7 and/or P8) and 10 were exclusive to these environments. *Dichanthelium aequivaginatum* (Swallen) Zuloaga stood out, occurring in four of the five less urbanized spots. In turn, 13 species occurred in urban areas (P2, P4 and/or P5), five of which were exclusive to these points. *Urochloa arrecta* (Hack. *ex* T.Durand & Schinz) Morrone & Zuloaga was the only species found in all three most anthropized points (table 1).

Emergent and amphibious life forms were the most abundant, corresponding to 30.4% of the species (n = 7), followed by exclusively amphibious (26.1%; n = 6), exclusively emergent (21.7%; n = 5), fixed submerged (13%; n = 3), and free floating and floating leaves (4.4%; n = 1 each) (table 1). The species surveyed in the present study are distinguished by diverse vegetative and reproductive morphological characters, such as the presence and/or absence of a leaf blade, the presence and/or absence of trichomes on the stem, phyllotaxy of leaves,

shape of the leaf blade, floral symmetry, number and color of tepals, concrescence of the gynoecium, and the biological form (see identification key below).

Dichanthelium aequivaginatum (Swallen) Zuloaga (Poaceae) is reported here for the first time from the Brazilian Amazon and the Northern region of Brazil.

1. Plants without flowers, fruits or seeds (ferns)
   2. Herbs not rooted in substrate, floating; fronds entire, frond blades suborbicular to orbicular; heterosporous ..... *Salvinia auriculata*
   2. Herbs rooted in substrate; fronds pinnate, frond blades lanceolate to elliptical; homosporous ..... *Christella dentata*
1. Plants with flowers, fruits or seeds (basal angiosperms, monocots or eudicots)
   3. Carpels not plicate, with margins sealed by secretion (basal angiosperms)
      4. Leaves submerged, presence of heterophylly; flowers with 6 tepals, yellow ..... *Cabomba aquatica*
      4. Leaves floating, absence of heterophylly; flowers with more than 6 tepals, white to cream ..... *Nymphaea rudgeana*
   3. Carpels plicate, with margins sealed by post-genital fusion of epidermis (monocots or eudicots)
      5. Plants with leaf blades with usually brochidodromous, never parallelodromous venation; pollen grains predominantly tricolpate or tricolpate-derived (eudicots)
         6. Leaves alternate
            7. Leaves with stipules; leaf blades with crenulate margin; petals white-pink ..... *Sauvagesia erecta*
            7. Leaves without stipules; leaf blades with entire margin; petals yellow
               8. Stem glabrous; flowers with four petals ..... *Ludwigia hyssopifolia*
               8. Stem pilose; flowers with five petals ..... *Ludwigia leptocarpa*
         6. Leaves opposite
            9. Leaf blades orbicular to broad-oval; petals white ..... *Bacopa aubletiana*
            9. Leaf blades linear to oblanceolate; petals white-lilac ..... *Bacopa aquatica*
      5. Plants with leaf blades with parallelodromous venation or rarely without leaf blades; monosulcate pollen grains (monocots)
         10. Leaves reduced to sheaths, without leaf blades ..... *Eleocharis interstincta*
         10. Leaves with developed leaf blades
            11. Leaves petiolate; leaf blades wide ovate, reniform or slightly cordate
               12. Flowers zygomorphic; petals white; gynoecium syncarpous ..... *Heteranthera reniformis*
               12. Flowers actinomorphic; petals yellow; gynoecium apocarpous ..... *Limnocharis flava*
            11. Leaves sessile; leaf blades linear to lanceolate
               13. Plants fixed submerged
                  14. Leaves alternate ..... *Tonina fluviatilis*
                  14. Leaves whorled ..... *Apalanthe granatensis*
               13. Plants emergent and/or amphibious
                  15. Floral scape quinquangular ..... *Fuirena umbellata*
                  15. Floral scape triangular or cylindrical
                     16. Floral scape triangular
                        17. Glumes spiraled ..... *Rhynchospora corymbosa*
                        17. Glumes distichous
                           18. Leaf blades shorter than involucral bracts; involucral bracts 2-3, glabrous; stamens 3 ..... *Cyperus haspan*
                           18. Leaf blades as long or longer than involucral bracts; involucral bracts 6-10, partially pilose; stamen 1
                              19. Spikelet with persistent rachilla, oval; fertile glumes deciduous ..... *Cyperus luzulae*
                              19. Spikelet with deciduous rachilla, linear to cylindrical; fertile glumes persistent ..... *Cyperus odoratus*
                     16. Floral scape cylindrical
                        20. Leaves spiraled; presence of mucilage at the base of the leaves; flowers dichlamydeous ..... *Xyris fallax*
                        20. Leaves distichous; absence of mucilage at the base of the leaves; flowers achlamydeous
                           21. Leaves without ligule ..... *Echinochloa colona*
                           21. Leaves with ligule
                              22. Nodes glabrous; leaf blades glabrous ..... *Urochloa arrecta*
                              22. Nodes pilose; leaf blades pilose toward the base at the adaxial surface …..... *Dichanthelium aequivaginatum*

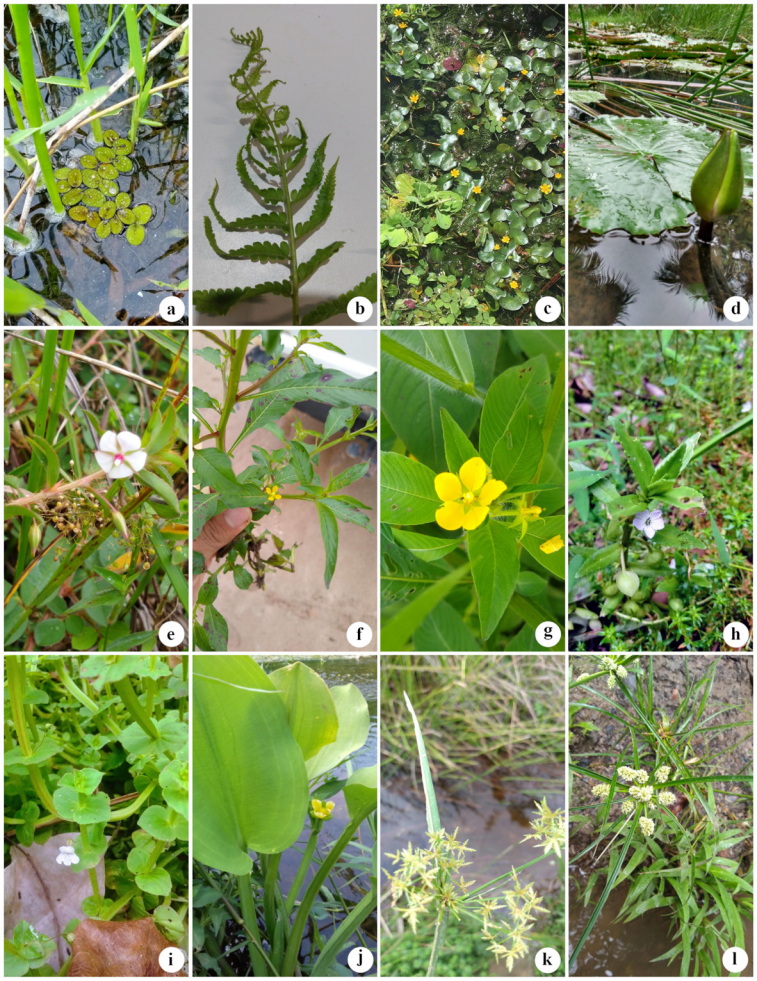

Figure 3. Macrophytes of the Capitão Poço river micro-basin, State of Pará, Eastern Amazon, Brazil. a. *Salvinia auriculata* Aubl. b. *Christella dentata* (Forssk.) Brownsey & Jermy. c. *Cabomba aquatica* Aubl. d. *Nymphaea rudgeana* G.Mey. e. *Sauvagesia erecta* L. f. *Ludwigia hyssopifolia* (G.Don) Exell. g. *Ludwigia leptocarpa* (Nutt.) H.Hara. h. *Bacopa aquatica* Aubl. i. *Bacopa aubletiana* Scatigna. j. *Limnocharis flava* (L.) Buchenau. k. *Cyperus haspan* L. l. *Cyperus luzulae* (L.) Retz.

Table 1. List of species of macrophytes in the eight sampling sites (P1, P2, P3, P4, P5, P6, P7, and P8) surveyed in the Capitão Poço river micro-basin, Pará, Brazil, and respective vouchers. Asterisks (*) indicate the most urbanized sampling sites. Biological Forms: A: amphibious. EM: emergent. EM/A: emergent/amphibious. FF: fixed with floating leaves. FL: free floating. FS: fixed submerged.

Families/Species	Biological forms	Vouchers	Sampling sites							
			P1	P2*	P3	P4*	P5*	P6	P7	P8
Ferns										
Salviniaceae										
Salvinia auriculata Aubl. (Fig. 3 a)	FL	*W.C.R. Soares 6*		X					X	
Thelypteridaceae										
Christella dentata (Forssk.) Brownsey & Jermy (Fig. 3 b)	EM/A	*L.S. Carvalho 35*							X	X
Basal angiosperms										
Cabombaceae										
Cabomba aquatica Aubl. (Fig. 3 c)	FS	*L.S. Carvalho 6*	X	X	X	X	X	X	X	X
Nymphaeaceae										
Nymphaea rudgeana G.Mey. (Fig. 3 d)	FF	*W.C.R. Soares 17*	X	X	X	X	X	X	X	X

continue

Table 1 (continuation)

Families/Species	Biological forms	Vouchers	Sampling sites							
			P1	P2*	P3	P4*	P5*	P6	P7	P8
Eudicots										
Ochnaceae										
Sauvagesia erecta L. (Fig. 3 e)	A	*W.C.R. Soares 15*					X			
Ludwigia hyssopifolia (G.Don) Exell (Fig. 3 f)	A	*W.C.R. Soares 3*				X				
Ludwigia leptocarpa (Nutt.) H.Hara (Fig. 3 g)	A	*L.S. Carvalho 19*	X							
Plantaginaceae										
Bacopa aquatica Aubl. (Fig. 3 h)	EM	*L.S. Carvalho 26*						X		
Bacopa aubletiana Scatigna (Fig. 3 i)	EM/A	*W.C.R. Soares 9*	X		X			X		
Monocots										
Alismataceae										
Limnocharis flava (L.) Buchenau (Fig. 3 j)	EM	*W.C.R. Soares 5*				X	X			
Cyperaceae										
Cyperus haspan L. (Fig. 3 k)	A	*W.C.R. Soares 16*		X	X				X	
Cyperus luzulae (L.) Retz. (Fig. 3 l)	A	*W.C.R. Soares 14*						X		
Cyperus odoratus L. (Fig. 4 a)	A	*L.S. Carvalho 30*				X			X	
Eleocharis interstincta (Vahl) Roem. & Schult. (Fig. 4 b)	EM	*L.S. Carvalho 2*		X	X	X	X		X	X
Fuirena umbellata Rottb. (Fig. 4 c)	EM/A	*L.S. Carvalho 31*		X	X					
Rhynchospora corymbosa (L.) Britton (Fig. 4 d)	EM/A	*L.S. Carvalho 22*							X	X
Eriocaulaceae										
Tonina fluviatilis Aubl. (Fig. 4 e)	FS	*L.S. Carvalho 33*			X					
Hydrocharitaceae										
Apalanthe granatensis (Humb. & Bonpl.) Planch. (Fig. 4 f)	FS	*L.S. Carvalho 18*			X		X	X		
Poaceae										
Dichanthelium aequivaginatum (Swallen) Zuloaga (Fig. 4 g)	EM/A	*W.C.R. Soares 13*	X		X			X		X
Echinochloa colona (L.) Link (Fig. 4 h)	EM	*L.S. Carvalho 20*			X					
Urochloa arrecta (Hack. *ex* T.Durand & Schinz) Morrone & Zuloaga (Fig. 4 i)	EM/A	*W.C.R. Soares 19*		X		X	X			
Pontederiaceae										
Heteranthera reniformis Ruiz & Pav. (Fig. 4 j)	EM	*W.C.R. Soares 2*				X	X			

continue

Table 1 (continuation)

Families/Species	Biological forms	Vouchers	Sampling sites							
			P1	P2*	P3	P4*	P5*	P6	P7	P8
Xyridaceae										
Xyris fallax Malme (Fig. 4 k-l)	EM/A	*W.C.R. Soares 11*								X
Species richness			3	4	8	5	5	5	4	4

Figure 4. Macrophytes of the Capitão Poço river micro-basin, State of Pará, Eastern Amazon, Brazil. a. *Cyperus odoratus* L. b. *Eleocharis interstincta* (Vahl) Roem. & Schult. c. *Fuirena umbellata* Rottb. d. *Rhynchospora corymbosa* (L.) Britton e. *Tonina fluviatilis* Aubl. f. *Apalanthe granatensis* (Humb. & Bonpl.) Planch. g. *Dichanthelium aequivaginatum* (Swallen) Zuloaga h. *Echinochloa colona* (L.) Link i. *Urochloa arrecta* (Hack. *ex* T.Durand & Schinz) Morrone & Zuloaga j. *Heteranthera reniformis* Ruiz & Pav. k-l. *Xyris fallax* Malme.

Discussion

We found a relatively lower number of macrophyte species in the Capitão Poço river micro-basin (19 genera and 23 species in eight sampled sites) than in other basins in Pará State. Fares *et al.* (2020a) recognized 49 species of 23 families in 30 sampling points (including streams, lakes and ponds) in the basin of the Capim river, and Fares *et al.* (2021) identified 50 species and 38 genera in 36 localities (also including streams, lakes and ponds) inserted in the Capim river and Acará-Mirim river basins. More recently, Bomfim *et al.* (2023) recorded 36 species and 30 genera of macrophytes in 17 streams associated with the Capim river basin. However, the number of sites sampled in the present study was smaller than in these studies. Thus, we believe that the expansion of sampling to other localities of Capitão Poço or the inclusion of different ecosystems such as lakes in future samplings may result in higher local richness, possibly similar to the abovementioned studies. Furthermore, 34.8% of the species occurred exclusively in a single locality (predominantly in the less urbanized sites), pointing to the importance of surveying the aquatic flora in multiple areas.

Cyperaceae and Poaceae were the families that most contributed to local richness, a recurrent pattern in inventories of the aquatic flora, mainly in lotic environments (Torres *et al.* 2016, Lopes *et al*. 2019, Nunes 2020, Almeida & Fabricante 2021, Fares *et al.* 2021). These two families are well represented probably due to their cosmopolitan distribution and large number of species, which is due to the presence of stolons, rhizomes and underground tubers that favor vegetative propagation (Pinheiro & Jardim 2015, Kawakita *et al.* 2016). Onagraceae and Plantaginaceae also have significant richness in the Neotropics, being among the main families recorded in floristic studies of macrophytes (Araújo *et al*. 2012, Costa 2014, Sabino *et al.* 2015, Murphy *et al.* 2019). In these studies, Onagraceae is commonly represented by the genus *Ludwigia*, which has high plasticity and encompasses species with the most diverse biological forms, from amphibious to submerged, resulting in an outstanding ability to explore different environments (Pott & Pott 2000). The greater richness of the genera *Cyperus* and *Ludwigia* found here can be related to their reproductive and adaptive morphological structures that provide them with the ability to grow in the most diverse environments, even in the face of irregular rainfall throughout the year, traits that make them to be considered generalist and, often, invasive plants and weeds (Costa 2014). Furthermore, most of the species of *Cyperus* and *Ludwigia* are emergent or amphibious; the reduction of water level in lotic environments during less rainy seasons provides a heterogeneity of habitats, favouring germination, survival and development of these biological forms (Reid *et al.* 2016; Regmi *et al.* 2021).

The predominance of amphibious and emergent life forms is in line with reports by other authors for tropical areas in Brazil (Ferreira *et al.* 2011, Kufner *et al.* 2011, Sabino *et al.* 2015). This predominance is associated with anthropized environments subject to seasonal flooding, low depths, and species tolerance to water volume variation (Moreira *et al.* 2011, Santos 2014). This pattern was also previously observed in anthropized watersheds in Pará State, including one in the northeast of the State (Fares *et al.* 2020a, Bomfim *et al.* 2023).

The species found in this study are cosmopolitan, pantropical or neotropical with a wide distribution in the American continent. None of the species was restricted to Brazil or endemic to the Amazon (Tropicos 2023). However, we recorded a new occurrence for the Brazilian Amazon (*D. aequivaginatum*), in addition to *U. arrecta*, an invasive species recently described to occur in Pará State which is likely causing ecological damage, so that its eradication from the water bodies in the State has been recommended (Fares *et al.* 2020b). Furthermore, the present study contributes to the knowledge of the macrophyte species from Northern Brazil, adding to the checklist presented by Moura Júnior *et al*. (2015) and complemented by subsequent inventories (*e.g.* Bomfim *et al.* 2023) or records of punctual occurrences (*e.g.* Fares *et al.* 2020b). Here we report the occurrence of four species not previously listed as components of the aquatic flora of the North of Brazil: *Christella dentata* (Forssk.) Brownsey & Jermy, *Heteranthera reniformis* Ruiz & Pav., *Xyris fallax* Malme, in addition to *D. aequivaginatum*. Thus, we suggest that floristic-taxonomic studies of macrophytes in the hydrographic basins of the northeastern region of Pará State should be intensified in order to better understand the regional flora of this group.

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Conflict of interests

There is no conflict of interest.

Author contributions

Lucimar Silva Carvalho: performed the collection, processing and analysis of specimens; wrote the first draft of the manuscript.
Witalo Cleidson Rodrigues Soares: performed the collection, processing and analysis of specimens.
Felipe Fajardo Villela Antolin Barberena: supervised the findings of this work; wrote the first draft of the manuscript.
Thaisa Pegoraro Comassetto: conceived the idea; supervised the findings of this work.

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