Rodriguésia 72: e00312020. 2021
http://rodriguesia.jbrj.gov.br
DOI: http://dx.doi.org/10.1590/2175-7860202172117

Original Paper

Diversity of macrophytes in the Amazon deforestation arc: information on their distribution, life-forms and habits

Ana Luísa Biondi Fares[1,2,4,10], *Raimundo Luiz Morais de Sousa*[1,2,5], *Ely Simone Cajueiro Gurgel*[2,6], *André dos Santos Bragança Gil*[2,7], *Carlos Alberto Santos da Silva*[2,8] & *Thaísa Sala Michelan*[1,2,3,9,10]

Abstract

The Amazon possesses the largest fluvial system on the planet, harboring a diverse biota. Still, many species remain undescribed, because of the Amazon's immense scale and complexity, and because many habitats are now increasingly under pressure from anthropogenic activities. Macrophytes are important to physical and biological processes in aquatic ecosystems but remain poorly studied in Northern Brazil. The objective of this study was to provide a checklist of macrophyte species that occur in municipalities that form part of the Arc of Deforestation, Pará state, Brazil, bringing information on their habits and life-forms. We sampled 36 sites at three types of aquatic ecosystems (streams, ponds and lakes). In total, we recorded 50 species, 38 genera and 24 families. Most species were amphibious or emergent. Degraded streams have environmental characteristics similar to lentic habitats, which could provide more suitable habitats for macrophytes that otherwise would not occur in lotic habitats, thus explaining the higher diversity in these ecosystems. Macrophyte diversity in this region follows similar patterns to other Brazilian regions. This study contributes to the assessment of aquatic macrophytes in the Amazon, especially in more degraded regions, such as the Amazon deforestation arc.
Key words: aquatic plants, checklist; Cyperaceae; Poaceae; aquatic biodiversity.

Resumo

A Amazônia possui o maior sistema fluvial do planeta, abrigando uma biota diversa. Mesmo assim, muitas espécies permanecem desconhecidas, devida imensa escala e complexidade deste bioma, e porque ele vem sofrendo com uma constante pressão antropogênica. Macrófitas são importantes para os processos físicos e biológicos dos ecossistemas aquáticos, porém ainda são pouco estudadas no Norte do Brasil. O objetivo deste estudo é fornecer uma checklist de espécies de macrófitas que ocorrem em municípios que fazem parte do Arco do desmatamento, trazendo informações sobre seus hábitos e formas de vida. Nós amostramos 36 pontos distribuídos em três tipos de ecossistemas aquáticos (riachos, lagos e brejos). No total, registramos 50 espécies, 38 gêneros e 24 famílias. A maioria das espécies era emergente ou anfíbia. Riachos degradados apresentam características similares a ambientes lênticos, o que pode ter oferecido maior disponibilidade de habitat para macrófitas que provavelmente não ocorreriam em condições de ambientes lóticos, o que explicaria a diversidade neste tipo de ecossistema. A diversidade de macrófitas desta região segue a maioria dos padrões de outras regiões do Brasil. Este estudo contribui para a avaliação da diversidade de macrófitas aquáticas na Amazônia, especialmente em locais que sofrem impacto antrópico, como o Arco do Desmatamento.
Palavras-chave: plantas aquáticas, levantamento florístico, Cyperaceae, Poaceae, biodiversidade aquática.

See supplementary material at <https://doi.org/10.6084/m9.figshare.16869367.v1>

[1] Universidade Federal do Pará, Inst. Ciências Biológicas, Lab. Ecologia e Conservação (LABECO) e Lab. Ecologia de Produtores Primários (ECOPRO), Guamá, Belém, PA, Brazil.
[2] Museu Paraense Emílio Goeldi e Universidade Federal Rural da Amazônia, Coord. Botânica - COBOT, Prog. Pós-graduação em Ciências Biológicas, Botânica Tropical, Campus de Pesquisa, Terra Firme, Belém, PA, Brazil.
[3] Universidade Federal do Pará, Inst. Ciências Biológicas, Prog. Pós-Graduação em Ecologia, Guamá, Belém, PA, Brazil.
[4] ORCID: <https://orcid.org/0000-0002-2738-1670>. [5] ORCID: <https://orcid.org/0000-0002-0511-3501>. [6] ORCID: <https://orcid.org/0000-0002-9488-7532>.
[7] ORCID: <https://orcid.org/0000-0002-0833-9856>. [8] ORCID: <https://orcid.org/0000-0003-1776-4886>. [9] ORCID: <https://orcid.org/0000-0001-9416-0758>.
[10] Author for correspondence: afaresbiondilima@gmail.com; tsmichelan@ufpa.br

Introduction

The Amazon basin is the largest freshwater system on the planet. The great number and diversity of aquatic ecosystems that together constitute this biome (*i.e.* rivers, streams, lakes, floodplains, ponds, marshes and swamps), makes for an aquatic biota that is highly diverse, specialized and unique (Castello *et al.* 2013). Because of the Amazon's immense scale and diversity, assessing its biodiversity, and how those species are distributed, remains a great challenge for biologists. Many species have yet to be catalogued, because there are still many unexplored places, and also because this biome is under increased anthropogenic pressure (especially by land-use change; Castello *et al.* 2013; Malhi *et al.* 2014), which both causes loss of habitat and biodiversity, and is thus changing species distributions.

Plants are key components of aquatic ecosystems, contributing to both physical and biological processes (Thomaz & Cunha 2010; Bornette & Puijalon 2011). Macrophytes are essential to primary production and provide oxygen to waterbodies, along with phytoplankton (Esteves 2011). They take part in nutrient cycles (*e.g.*, carbon, nitrogen and phosphorus; Bornette & Puijalon 2011), and in sedimentation processes (Aoki *et al.* 2017). But, most importantly, macrophytes are food supply for primary consumers, and provide shelter and nurseries for other organisms *(e.g.*, fish, invertebrates and microorganisms; Thomaz & Cunha 2010; Bornette & Puijalon 2011). Thus, macrophytes augment habitat heterogeneity and complexity, which increases overall aquatic ecosystem biodiversity (Large & Prach 1999; Thomaz & Cunha 2010).

Macrophytes are distributed in several botanical groups, mainly the Pteridophyta and Spermatophyta, which include various families of lycophytes, ferns and angiosperms (Chambers *et al.* 2008). They possess a common feature: the development of various adaptative strategies throughout evolutionary history (related to morphology and physiology) that allowed them to colonize aquatic ecosystems (*i.e.* lakes, rivers, stream, reservoirs, coastal and estuarine regions, and falls) (Thomaz & Cunha 2010; Esteves 2011). Some macrophytes are abundant in human-altered environments, and serve as bioindicators of ecological and environmental condition of freshwater ecosystems (Kolada 2010; Alahuhta *et al.* 2014; Bleich *et al.* 2015; Kassaye *et al.* 2016; Poikane *et al.* 2018), including some species in Neotropical ecosystems (Fares *et al.* 2020a).

In accordance with other plant taxa, macrophyte diversity is highest in tropical areas, with most known diversity hotspots being found in the Neotropics (Chambers *et al.* 2008; Murphy *et al.* 2019). There are several publications about Amazonian macrophytes, including field identification guidebooks (Demarchi *et al.* 2018; Piedade *et al.* 2018), a book on anatomy and morphology (Guterres *et al.* 2008), along with ecological (Piedade *et al.* 2010; Bleich *et al.* 2015; Lopes *et al.* 2016), and floristic studies and checklists (Moura Junior *et al.* 2015; Abe *et al.* 2015; Costa *et al.* 2016). But few assess macrophyte occurrence in human-altered habitats, especially in the Amazon's deforestation arc (but see Bleich *et al.* 2015 for an ecological assessment in impacted areas).

The Northern region of Brazil (which contains most of the Brazilian Amazon) consists of 8 states and can be considered a priority area of aquatic plant conservation (Moura Júnior *et al.* 2015). Among those, the state of Pará has one of the highest numbers of macrophyte species records (Moura Júnior *et al.* 2015). Yet despite numerous floristic studies and records of botanical clades that include macrophytes (Mota & Koch 2016; Mota & Wanderley 2016; Pereira *et al.* 2017; Watanabe *et al.* 2017; Lima 2018; Maciel-Silva *et al.* 2018), the herbarium numbers are underestimated for this region (Moura Júnior *et al.* 2015), and there is a lack of macrophyte surveys in altered areas.

One way to assess the diversity of a place is through checklists. Floristic studies of macrophytes contribute to the knowledge of aquatic plant geographic distribution (Moura Júnior *et al.* 2013, 2015), and thus help filling Wallacean shortfalls (a fragmentary knowledge regarding species distribution) (Bini *et al.* 2006; Kozlowski *et al.* 2009). Additionally, the systematic recording of macrophytes through checklists can serve as subsidy for ecological studies on either micro or macroscales (Moura Júnior *et al.* 2013). For example, the information on species distribution can provide datasets for studies that test macroecological hypotheses, which need a high amount of species occurrence records for the distribution models (Carvalho *et al.* 2009; Murphy *et al.* 2019), or help with studies that aim to model predictions of species distribution in response to climate change (Ahahuhta *et al.* 2011). Hence, macrophyte checklists are primary surveys that can later support studies that help us understand aquatic biodiversity patterns.

Thus, the main objective of this study was to provide a checklist of macrophyte species that occur in the eastern Amazon, more specifically the municipalities of Paragominas and Tomé-Açu, landscapes that are heavily altered by anthropogenic activities, bringing information on their habits, life-forms, and the sites where they were found. We aim to answer the following questions: i) What is the number of macrophytes that occur in this region?; ii) What are their life-forms?; iii) What are the types of aquatic ecosystems/waterbodies where they can be found?; and iv) Does species composition change according to ecosystem type?

Materials and Methods

Study area

In July 2017 and May 2018, we sampled 36 sites, which comprise streams (23), lakes (7) and ponds (6) (Fig. 1a-c), located in the municipalities of Paragominas, Ipixuna do Pará and Tomé-açu, Pará, Brazil (Paragominas - Lat: 02º59'45"S; Long: 47º21'10"W and Ipixuna do Pará - Lat: 02º33'31"S; Long: 47º29'45"W, both inserted on the Capim River Basin, and Tomé-açu - Lat: 02°24'53"S, Long: 48°08'60"W, inserted on the Acará-mirim River Basin - Fig. 2). The climate is characterized as wet and hot (mean annual temperature: 26 ºC, mean air humidity: 81%, and mean annual precipitation: 1,800 millimeters) (Pinto *et al.* 2009). The vegetation of the area consists of large tropical rainforest fragments, intermixed with various human land uses (*e.g.*, agriculture, pasture, logging and mining activities; Pinto *et al.* 2009).

Study areas are in the world's largest remaining tropical forest, the Amazon, which is extremely important for global ecosystems services (*e.g.*, climatic regulation and biodiversity conservation), but also provides human-welfare benefits, such as economic goods, like timber and agricultural

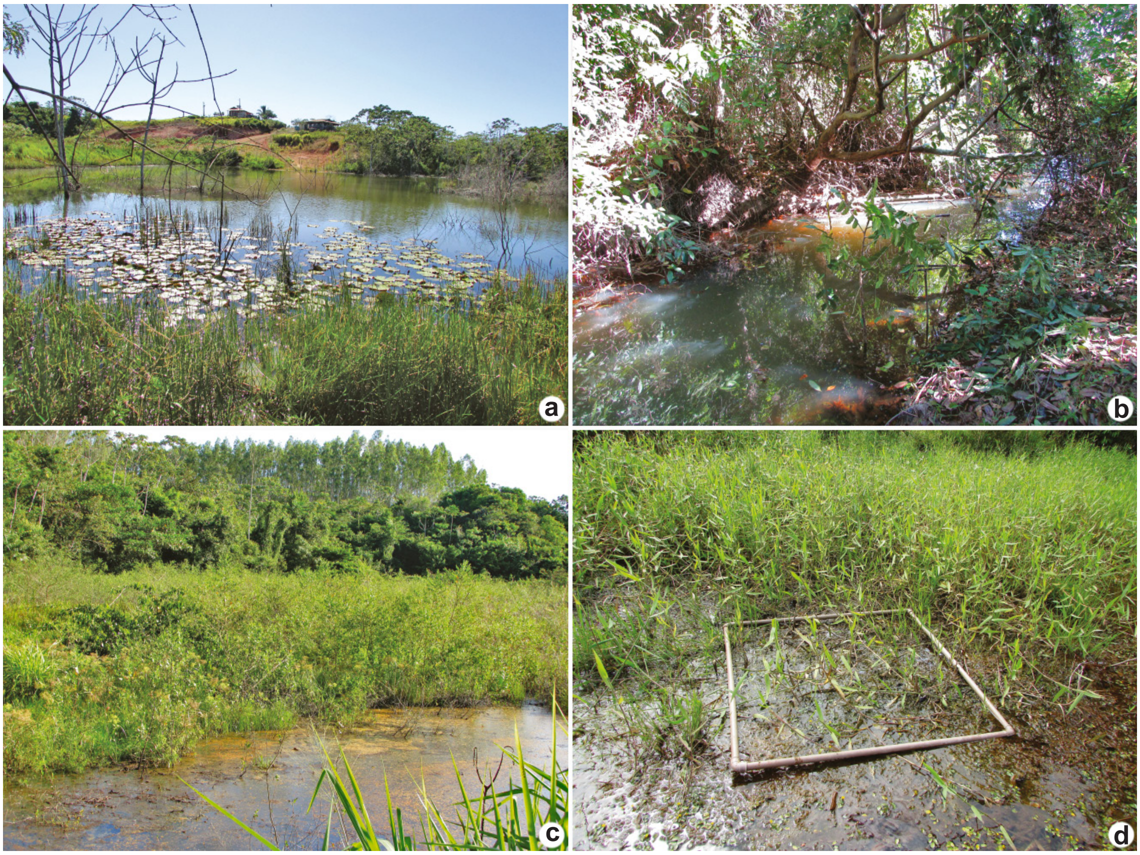

Figure 1 – a-d. Sampled environments and methodology applied – a. lake; b. stream; c. pond; d. the quadrat method.

products (Gardner *et al.* 2013). Specifically, the area known as the arc of deforestation comprises a forest area that was removed due to agricultural and road expansion in the 1970s and 90s (Fearnside 2005; Malhi *et al.* 2008). The rate of deforestation inside this "arc" is unsettling, comprising a large territory from the northwestern side of Maranhão, eastern, Southern and a western portion of Pará, western and northern Tocantins, the Midwestern and northern portion Mato Grosso, southern Amazonas. and all the States of Rondônia and Acre (Fearnside 2005).

As large areas have been shaped by human activities, it is important to understand and research thoroughly those locations, due to their importance to biodiversity conservation. How much those places could be threatened defines them as hotspots for research in understanding how human activities affect living organisms.

Biological sampling

We took notes of all macrophyte species (as number of species, brief description of the characteristics of the species and life-forms) that occurred in a 150 m transect of each aquatic ecosystem. To calculate macrophytes species composition within the transect, we used a PVC square measuring 1m² (Fig. 1d), in which the percentage of coverage (1–100 %) of each species present in the quadrat was measured by visual estimation. The quadrat method is widely used in ecological studies and has proven to give an efficient response in representing macrophyte community composition (Sass *et al.* 2010; Bleich *et al.* 2015). The quadrat was thrown randomly two times into the macrophyte mats, except for two sites, in which it was thrown only once, in sum totaling 70 quadrats.

The macrophytes were collected manually or using pruning shears. Where possible, species were identified in the field, and the non-identified material was collected following Herbarium techniques (Rotta *et al.* 2008). As our samples comprise active field samples, thus resulting in new collections for the area, all collected material was identified to the smallest possible taxonomic

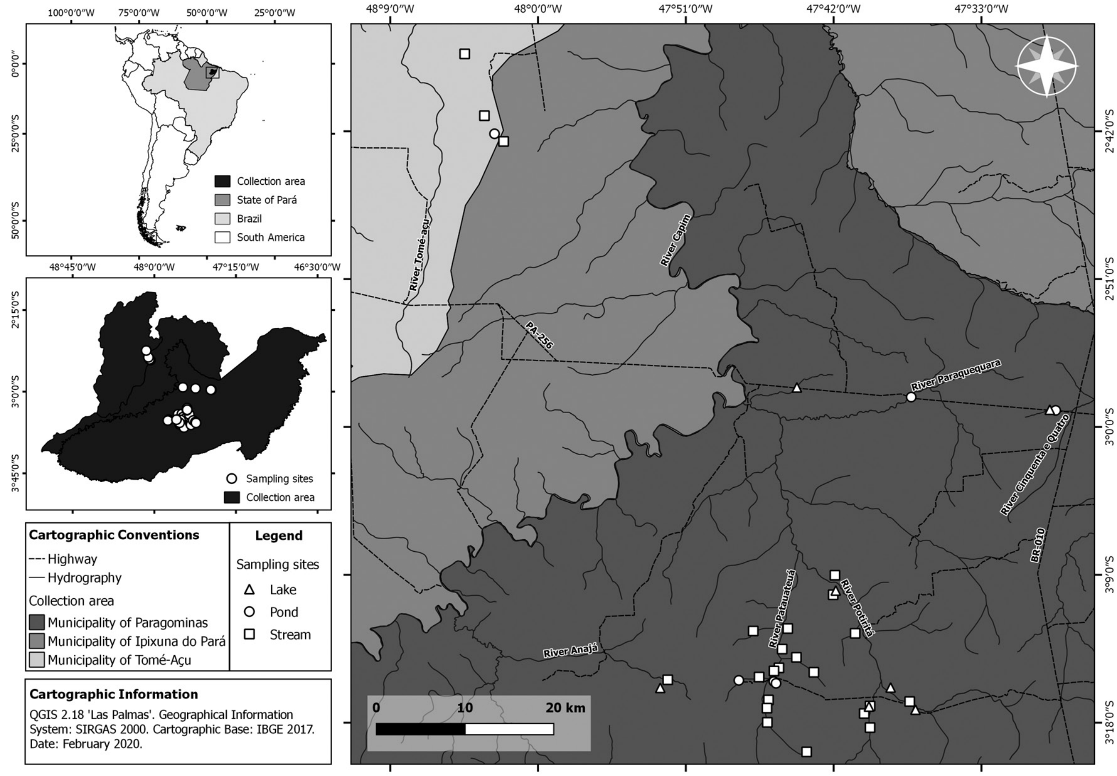

Figure 2 – Map showing the samples and each type of ecosystem (□ = Stream; Δ = Lake; ○ = Pond) of aquatic macrophytes in Pará state.

group using specialized literature (Pott & Pott 2000; Amaral *et al.* 2008; Lorenzi 2008), specialist consultation, and comparison with reference material deposited in the MG Herbarium, at the Museu Paraense Emílio Goeldi (MPEG), Pará, Brazil, where all fertile plants of this study were deposited, except for one species (*Urochloa arrecta* (Hack. *ex* T. Durand & Schinz) Morrone & Zuloaga), which was deposited at the Felisberto Camargo Herbarium (FG), at the Universidade Federal Rural da Amazônia. Species that were unfertile at the time of collection and/or with poor herborization could not be incorporated into herbarium collections and sometimes could not be determined at the specific level, therefore they do not have vouchers and/or are treated at the genus level. Botanical accepted names followed the Tropicos website (Tropicos.org 2020), the Plant List website (The Plant List 2013) as well as the Brazil Flora Group (Flora do Brasil 2020) to confirm species and authors names.

Life-forms were classified according to Esteves (2011), which divides macrophytes into seven groups: amphibious, emergent, epiphyte, floating-leaved, free-floating, free-submerged and rooted-submerged. They were also determined according to specialized literature (Pott & Pott 2000; Amaral *et al.* 2008), and national macrophyte checklists containing life-form information (Moura Júnior *et al.* 2013, 2015; Pivari *et al.* 2013; Abe *et al.* 2015), along with field observations.

Additionally, we calculated the frequency of occurrence of each species (the number of sites where a species was recorded) and recorded the type of waterbodies where they were found (stream, pond and lake). To assess change in species composition according to the type of ecosystem, we performed a Principal Coordinates Analysis (PCoA), using the "cmdscale" function of the vegan package (Oksanen *et al.* 2019). For this analysis, we considered each quadrat as a sample unit, and used a Bray-Curtis matrix for abundance-based composition. The species matrix was log-transformed. Graphs were plotted using the package ggplot2 (Wickham 2016) in the R program version 3.5.1 (R Core team 2018), where all analyses were performed.

Results and Discussion

We recorded 50 species, divided in 38 genera and 24 families of vascular plants, ferns and lycophytes (Tab. S1, available on supplementary material <https://doi.org/10.6084/m9.figshare.16869367.v1>), among different types of freshwater ecosystems. Total species richness per site varied from one to sixteen species, with 22% of species registered as singletons or doubletons.

The families Cyperaceae and Poaceae had the largest number of species: 15 and seven species, respectively (Fig. 3), which is in agreement with other studies that show a floristic representativeness of those families in Brazilian freshwater ecosystems (Pott & Pott 1997; Moura Júnior *et al.* 2013, 2015). Most other families were represented by only a single species (Fig. 3).

Eleocharis R. Br. (Cyperaceae) was the richest genus, with four species recorded, followed by *Rhynchospora* Vahl (Cyperaceae) and *Ludwigia* L. (Onagraceae), with three species each. *Calyptrocarya glomerulata* (Brongn.) Urb. and *Fuirena umbellata* Rottb. (Cyperaceae), the most frequent species, were recorded in 18 of 36 sites, followed by *Utricularia* sp L. (Lentibulariaceae, found in 17 sites), *Eleocharis interstincta* (Vahl) Roem. & Schult. (Cyperaceae, 17 sites) and *Cabomba aquatica* Aubl. (Cabombaceae, 14 sites). We also recorded an invasive species, *Urochloa arrecta* (Hack. *ex* T.Durand & Schinz) Morrone & Zuloaga (Poaceae), in eight sites (first record in this area; Fares *et al.* 2020b).

Utricularia sp proved to be one of the most abundant species, being considered, according to its life-form, free-submerged. This species usually occurs in environments with low levels of nutrients and with low water flow, and it can be used as a bioindicator of human disturbance in aquatic environments (Pott & Pott 2000; Raynal-Roques & Jérémie 2005). Along with *Utricularia* sp., the species *Cabomba aquatica* is also associated with open environments and may indicate loss of forest

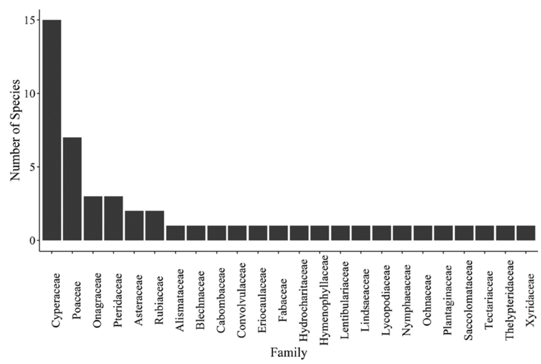

Figure 3 – Distribution of macrophyte species in each botanical family.

cover, as they are dominant in sites with low forest cover (Sass *et al.* 2010; Bleich *et al.* 2015), and can be supported by this study that focused on human-modified areas.

In this survey, we recorded five distinct macrophyte life-forms. The amphibious life-form had the largest number of species (30) which comprises 60% of total species richness, followed by emergent species, who accounted for 26% of total richness (13). Other life forms included rooted-submerged, with 8% (4 species), floating-leaved, with 4% (2), and free-submerged, with 2% (1) of total species richness (Fig. 4). It is important to identify the life-forms of macrophytes in aquatic ecosystems, because each one uses the resources in the water or in the sediment close to the margin differently (Mormul *et al.* 2010).

Other studies on Brazilian macrophytes (including the northern region) found that amphibious and/or emergent species are dominant, comprising more than half of overall macrophyte species richness (sometimes even close do 90%) (Pott & Pott 1997; Moura Júnior *et al.* 2013, 2015). This must be due to their overall resilience to a multitude of environmental pressures found in aquatic ecosystem (Lacoul & Freedman 2006; Moura Júnior *et al.* 2015), including drought resistance. As these species live in the aquatic-terrestrial interface, and some of them can change their morphology and physiology according to water availability (Esteves 2011), amphibious and emergent species can persist even in the dry season, which makes them highly adaptable and resistant to environmental change.

Across different ecosystems, streams had the most macrophyte species records (but it is important to emphasize we had more sites in streams if compared with lentic sites) (See Fig. 4). By assessing the variation in species composition between the three types of environments using PCoA, the analysis reduced the dimensionality of the data by explaining 30.49% of the observed variation in its first two axes (Fig. 5). However, no pattern of separation of this composition was observed between the types of ecosystems in this study, as it is possible to see with the overlapping of sampling sites regardless of the type of environment that was sampled (Fig. 5). Lentic habitats often show higher macrophyte diversity compared with lotic habitats, due to abiotic factors favoring their occurrence, *e.g.* high light incidence on the water column, low water flow, increased nutrient content and others (Lacoul & Freedman 2006; Moura Júnior *et al.* 2011, 2015). We believe that the fact we did not find similar results in our study is because degraded streams (like some we sampled) tend to have the same characteristics cited above (Miserendino *et al.* 2011), making them similar to lentic environments. This can give advantage to species that are not adapted to currents or that are shade-tolerant, and thus increasing species richness and heterogeneity on those systems. Still, 20 species were recorded in all habitats (see Tab. S1, available on supplementary material <https://doi.org/10.6084/m9.figshare.16869367.v1>).

Thus, we conclude that aquatic ecosystems located in the Arc of Deforestation have a high diversity of macrophytes. Cyperaceae and Poaceae have the highest number of species. There is also a

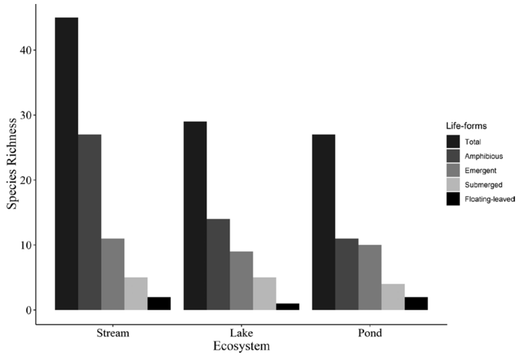

Figure 4 – Macrophyte species richness of the whole community (total richness) and of each life-form (amphibious, emergent, submerged and floating-leaved) found in each type of ecosystem (stream, lake and pond).

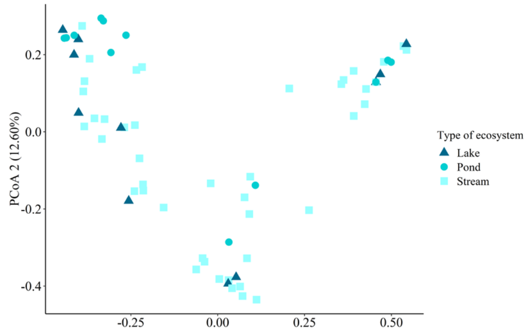

Figure 5 – Result of PCoA with species composition and type of ecosystem. ■ = Stream; ▲ = Lake; ● = Pond.

great range of life-forms occurring in these areas, even if most species belong to the emergent or amphibious group. Still, degraded streams often present similar environmental characteristics to lentic habitats, which may have increased habitat availability to macrophytes that otherwise would not occur in truly lotic habitats. Our results are reflective of diversity patterns found in other Brazilian regions. This study contributes to the assessment of aquatic macrophytes in the Amazon, especially in sites that suffer from anthropogenic impacts. Thus, we hope our results contribute to wider understanding on the distribution of aquatic plants the Amazon biome, and future ecological and floristic studies.

Acknowledgements

AL Fares and RLM Sousa are thankful to Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001, for their scholarships. We thank the Aquatic Biota field crew (Lenize Calvão, Leandro Juen, Ana Luiza Andrade, Calebe Maia, Carina Paiva, Gilberto Salvador, Naiara Torres and Thiago Barbosa), for helping with field sampling; and Alistair John Campbell, for reviewing the english.

This work was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001, Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq (process 433125/2018-7), and Hydro Paragominas Company, for supporting the research projects "Effects of soil use on diversity and ecophysiology on the riparian vegetation, aquatic macrophytes and plankton in streams and lagoons in mining areas of Paragominas, Pará, Brazil" and "Monitoring Aquatic Biota of Streams on Areas of Paragominas Mining SA, Pará, Brazil" through the Biodiversity Research Consortium Brazil-Norway (BRC). This paper is number 19 in the publication series of the BRC.

References

Abe DS, Sidagis-Galli C, Matsumura-Tundisi T, Tundisi JEM, Blanco FP, Faria CRL & Tundisi JG (2015) Additional list of species of aquatic macrophytes in the lower basin of the Xingu River. Brazilian Journal of Biology 75: 70-77.

Alahuhta J, Kanninen A, Hellsten S, Vuori KM, Kuoppala M & Hämäläinen H (2014) Variable response of functional macrophyte groups to lake characteristics, land use, and space: implications for bioassessment. Hydrobiologia 737: 201-214.

Amaral MCE, Bittrich V, Faria AD, Anderson LO & Aona LYS (2008) Guia de campo para plantas aquáticas e palustres do estado de São Paulo. Holos, Editora, Ribeirão Preto. 452p.

Aoki C, Teixeira-Gamarra MC, Gamarra RM, Medeiros SCH, Pott VJ, Damasceno-Junior GA, Pott A & Scremin-Dias E (2017) Abiotic factors drive the structure of aquatic plant assemblages in riverine habitats of the Brazilian "Pantanal". Revista Brasileira de Botânica 40: 405-415.

Bini LM, Diniz-Filho JAF, Rangel TFLVB, Bastos RP & Pinto MP (2006) Challenging wallacean and linnean shortfalls: knowledge gradients and conservation planning in a biodiversity hotspot. Diversity and Distributions 12: 475-482.

Bleich ME, Piedade MTF, Mortati AF & André T (2015) Autochthonous primary production in southern Amazon headwater streams: novel indicators of altered environmental integrity. Ecological Indicators 53: 154-161.

Bornette G & Puijalon S (2011) Response of aquatic plants to abiotic factors: A review. Aquatic Sciences 73: 1-14.

Carvalho P, Bini LM, Diniz-Filho JAF & Murphy KJ (2009) A macroecological approach to study aquatic macrophyte distribution patterns. Acta Limnologica Brasiliensia. 21: 169-174.

Castello L, Mcgrath DG, Hess LL, Coe MT, Lefebvre PA, Petry P, Macedo MN, Renó VF & Arantes CC (2013) The vulnerability of Amazon freshwater ecosystems. Conservation Letters 6: 217-229.

Chambers PA, Lacoul P, Murphy KJ & Thomaz SM (2008) Global diversity of aquatic macrophytes in freshwater. Hydrobiologia 595: 9-26.

Costa SM, Barbosa TDM, Bittrich V & Amaral MCE do (2016) Floristic survey of herbaceous and subshrubby aquatic and palustrine angiosperms of Viruá National Park, Roraima, Brazil. PhytoKeys 58: 21-48.

Demarchi LO, Lopes A, Ferreira AB & Piedade MTF (2018) Macrófitas aquáticas do Lago Amazônico. Editora INPA, Manaus. 44p.

Esteves FA (2011) Fundamentos de Limnologia. 3rd ed. Interciência, Rio de Janeiro. 826p.

Fares ALB, Calvão LB, Torres NR, Gurgel ESC & Michelan TS (2020a) Environmental factors affect macrophyte diversity on Amazonian aquatic ecosystems inserted in an anthropogenic landscape. Ecological Indicators 113: 106-231.

Fares ALB, Nonato FAS & Michelan TS (2020b) New records of the invasive macrophyte, *Urochloa arrecta* extend its range to eastern Brazilian Amazon altered freshwater ecosystems. Acta Amazonica 50: 133-137.

Fearnside PM (2005) Deforestation in Brazilian Amazonia: history, rates, and consequences. Conservation Biology 19: 680-688.

Flora do Brasil (2020) Jardim Botânico do Rio de Janeiro. Avaiable at <http://floradobrasil.jbrj.gov.br/>. Access on 25 October 2021.

Gardner TA, Ferreira J, Barlow J, Lees AC, Parry L, Vieira ICG, Berenguer E, Abramovay R, Aleixo A, Andretti C, Aragão LEOC, Araújo I, Ávila WS, Bardgett RD, Batistella M, Begotti RA, Beldini T, Blas DE, Braga RF, Braga DL, Brito JG, Camargo PB, Santos FC, Oliveira VC, Cordeiro ACN, Cardoso TM, Carvalho DR, Castelani SA, Chaul JCM, Cerri CEP, Costa FA, Costa CDF, Coudel E, Coutinho AC, Cunha D, D'Antona Á, Dezincourt J, Dias-Silva K, Durigan M, Esquerdo JCDM, Feres J, Ferraz SFB, Ferreira AEM, Fiorini AC, Silva LVF, Frazão FS, Garrett R, Gomes AS, Gonçalves KS, Guerrero JB, Hamada N, Hughes RM, Igliori DC, Jesus EC, Juen L, Junior M, Oliveira Junior JMB, Oliveira Junior RC, Souza Júnior C, Kaufmann P, Korasaki V, Leal CG, Leitão R, Lima N, Almeida MFL, Lourival R, Louzada J, Mac Nally R, Marchand S, Maués MM, Moreira FMS, Morsello C, Moura N, Nessimian J, Nunes S, Oliveira VHF, Pardini R, Pereira HC, Pompeu PS, Ribas CR, Rossetti F, Schmidt FA, Silva R, Silva RCVM, Silva TFMR, Silveira J, Siqueira JV, Carvalho TS, Solar RRC, Tancredi NSH, Thomson JR, Torres PC, Vaz-de-Mello FZ, Veiga RCS, Venturieri A, Viana C, Weinhold D, Zanetti R & Zuanon J (2013) A social and ecological assessment of tropical land uses at multiple scales: the sustainable Amazon network. Philosophical Transactions of the Royal Society B: Biological Sciences 368: 1-12.

Guterres MG, Marmontel M, Ayub DM, Singer RF & Singer RB (2008) Anatomia e morfologia de plantas aquáticas da Amazônia utilizadas como potencial alimento por Peixe-boi amazônico. Instituto de Desenvolvimento Sustentável Mamirauá - IDSM, Belém. 187p.

Kassaye YA, Skipperud L, Einset J & Salbu B (2016) Aquatic macrophytes in Ethiopian Rift Valley lakes; their trace elements concentration and use as pollution indicators. Aquatic Botany 134: 18-25.

Kolada A (2010) The use of aquatic vegetation in lake assessment: testing the sensitivity of macrophyte metrics to anthropogenic pressures and water quality. Hydrobiologia 656: 133-147.

Kozlowski G, Rion S, Python A & Riedo S (2009) Global conservation status assessment of the threatened aquatic plant genus Baldellia (Alismataceae): challenges and limitations. Biodiversity and Conservation 18: 2307-2325.

Lacoul P & Freedman B (2006) Environmental influences on aquatic plants in freshwater ecosystems. Environmental Reviews 14: 89-136.

Large ARG & Prach K (1999) Plants and water in streams and rivers. *In*: Baird AJ & Wilby RL (eds.) Ecohydrology: plants and water in terrestrial and aquatic environments. Routledge, London. Pp. 237-268.

Lima CT (2018) Flora das cangas da Serra dos Carajás, Pará, Brasil: Nymphaeaceae. Rodriguésia 69: 153-156.

Lopes A, Parolin P & Piedade MTF (2016) Morphological and physiological traits of aquatic macrophytes respond to water chemistry in the Amazon Basin: an example of the genus *Montrichardia* Crueg (Araceae). Hydrobiologia 766: 1-15.

Lorenzi H (2008) Plantas daninhas do Brasil: terrestres, aquática, parasitas e toxicas. 4th ed. Instituto Plantarum, Nova Odessa. 640p.

Maciel-Silva JF, Nunes CS & Gil ASB (2018) The genus *Eleocharis* (Cyperaceae) in the restinga of Pará state, Brazil. Rodriguésia 69: 1813-1824.

Malhi Y, Timmons R, Betts RA, Killeen TJ, Li W & Nober CA (2008) Climate change, deforestation, and the fate of the Amazon science 319: 169-172.

Malhi Y, Gardner TA, Goldsmith GR, Silman MR & Zelazowski P (2014) Tropical forests in the anthropocene. Annual Review of Environment and Resources 39: 125-159.

Miserendino ML, Casaux R, Archangelsky M, Prinzio CY Di, Brand C & Kutschker AM (2011) Assessing land-use effects on water quality, in-stream habitat, riparian ecosystems and biodiversity in Patagonian northwest streams. Science of the Total Environment 409: 612-624.

Mormul RP, Ferreira FA, Michelan TS, Carvalho P, Silveira MJ & Thomaz SM (2010) Aquatic macrophytes in the large, sub-tropical Itaipu Reservoir, Brazil. Revista de Bíologia Tropical, 58: 1437-1452.

Mota NFDO & Koch AK (2016) Flora das cangas da Serra dos Carajás, Pará, Brasil: Mayacaceae. Rodriguesia 67: 1417-1422.

Mota NFDO & Wanderley MDGL (2016) Flora das cangas da Serra dos Carajás, Pará, Brasil: Xyridaceae. Rodriguesia 67: 1499-1503.

Moura Júnior EG, Lima LF, Silva SSL, Paiva RMS, Ferreira FA, Zickel CS & Pott A (2013) Aquatic macrophytes of Northeastern Brazil: checklist, richness, distribution and life forms [with erratum]. Check List 9: 298.

Moura Júnior EG, Paiva RMS, Ferreira AC, Pacopahyba LD, Tavares AS, Ferreira FA & Pott A (2015) Updated checklist of aquatic macrophytes from Northern Brazil. Acta Amazonica 45: 111-132.

Moura Júnior EG, Abreu MC, Severi W & Lira GAST (2011) O gradiente rio-barragem do reservatório de Sobradinho afeta a composição florística, riqueza e formas biológicas das macrófitas aquáticas? Rodriguésia 62: 731-742.

Murphy K, Efremov A, Davidson TA, Molina-Navarro E, Fidanza K, Betiol TCC, Chambers P, Grimaldo JT, Martins SV, Springuel I, Kennedy M, Mormul RP, Dibble E, Hofstra D, Lukács BA, Gebler D, Baastrup-Spohr L & Urrutia-Estrada J (2019) World distribution, diversity and endemism of aquatic macrophytes. Aquatic Botany 158: 103127.

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHH, Szoecs E & Wagner H (2019) vegan: Community Ecology Package. Available at <https://cran.r-project.org/web/packages/vegan/index.html>. Access on 23 March 2020.

Pereira JBS, Arruda AJ & Salino A (2017) Flora of the cangas of Serra dos Carajás, Pará, Brazil: Isoetaceae. Rodriguésia 68: 853-857.

Piedade MTF, Junk W, D'Ângelo SA, Wittmann F, Schöngart J, Barbosa KMN & Lopes A (2010) Aquatic herbaceous plants of the Amazon floodplains: state of the art and research needed. Acta Limnologica Brasiliensia 22: 165-178.

Piedade MTF, Lopes A, Demarchi LO, Junk W, Wittmann F, Schöngart J & Cruz J (2018) Guia de campo de herbáceas aquáticas: várzea Amazônica. Editora INPA, Manaus. 300p.

Pinto A, Amaral P, Souza Jr C, Veríssimo A, Salomão R, Gomes G & Balieiro C (2009) Diagnóstico socioeconômico e florestal do município de Paragominas. Instituto do Homem e Meio Ambiente da Amazônia - Imazon, Belém. 65p.

Pivari MOD, Viana PL & Leite FSF (2013) The aquatic macrophyte flora of the pandeiros river wildlife sanctuary, minas Gerais, Brazil. Check List 9: 415-424.

Poikane S, Portielje R, Denys L, Elferts D, Kelly M, Kolada A, Mäemets H, Phillips G, Søndergaard M, Willby N & van den Berg MS (2018) Macrophyte assessment in European lakes: diverse approaches but convergent views of 'good' ecological status. Ecological Indicators 94: 185-197.

Pott VJ & Pott A (1997) Checklist das macrófitas aquáticas do Pantanal, Brasil. Acta Botanica Brasilica 11: 215-227.

Pott VJ & Pott A (2000) Plantas aquáticas do Pantanal. Embrapa Comunicação para Transferência de Tecnologia, Brasília. 404p.

R Core Team (2018) R: a language and environment for statistical computing. Available at <https://www.r-project.org/>. Access on 23 March 2020.

Raynal-Roques A & Jérémie J (2005) Biologie diversity in the genus *Utricularia* (Lentibulariaceae). Acta botanica gallica 152: 177-186.

Rotta E, Carvalho LC & Beltrami MZ (2008) Manual de prática de coleta e herborização de material botânico [recurso eletrônico]. Embrapa Florestas, Colombo. 31p.

Sass LL, Bozek MA, Hauxwell JA, Wagner K & Knight S (2010) Response of aquatic macrophytes to human land use perturbations in the watersheds of Wisconsin lakes, USA. Aquatic Botany 93: 1-8.

The Plant List (2013) Version 1.1. Available at <http://www.theplantlist.org/>. Access on 23 March 2020.

Thomaz SM & Cunha ER (2010) The role of macrophytes in habitat structuring in aquatic ecosystems: methods of measurement, causes and consequences on animal assemblages' composition and biodiversity. Acta Limnologica Brasiliensia 22: 218-236.

Tropicos.org (2020) Missouri Botanical Garden. Available at <http://www.tropicos.org>. Access on 23 March 2020.

Watanabe MTC, Oliveira-Chagas EC & Giulietti AM (2017) Flora das cangas da Serra dos Carajás, Pará, Brasil: Eriocaulaceae. Rodriguesia 68: 965-978.

Wickham H (2016) ggplot2: elegant graphics for data analysis. Springer-Verlag, New York. 260p.

Area Editor: Dr. Pedro Viana
Received in May 12, 2020. Accepted in November 05, 2020.