ECOLOGY OF AQUATIC MACROPHYTES IN BRAZIL: THE LEGACY OF FRANCISCO DE ASSIS ESTEVES

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Supplementary Material

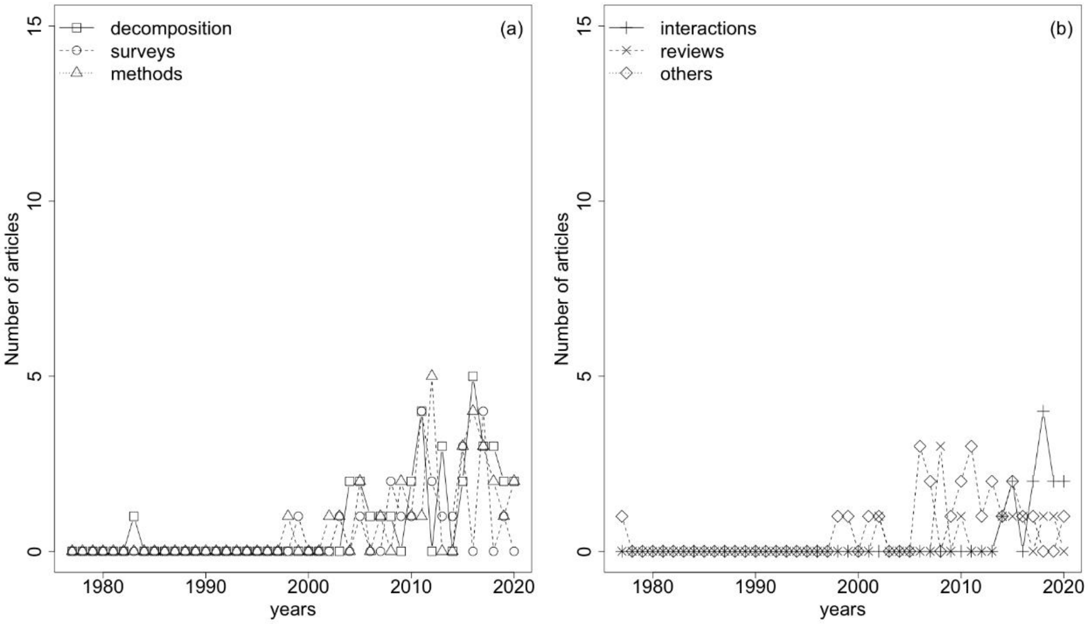

Figure S1. Temporal trends of the number of articles published (indexed in the Web of Science) in different subjects.

Table S1. List of the first 10 articles appearing in Web of Science using the search string TOPIC: ("macrophyte*") AND ADDRESS: (Brasil or Brazil)

Howard-Williams, C. & Junk, W. J. (1977). The chemical composition of Central Amazonian aquatic macrophytes with special reference to their role in the ecosystem. ArchivesfürHydrobiologia 79, 446–464.

Junk, W. J. (1982). On the development of aquatic macrophytes in Curua-Una, the first man-made lake in central Amazonia. *Archiv fur Hydrobiologie,* 95(1), 169-180.

Esteves, F. A., & Barbieri, R. (1983). Dry weight and chemical changes during decomposition of tropical macrophytes in lobo reservoir—Sao Paulo, Brazil. *AquaticBotany*, *16*(3), 285-295.

Soares, M. G. D. M., Almeida, R. G., &Junk, W. J. (1986). The trophic status of the fish fauna in Lago Camaleão, a macrophyte dominated floodplain lake in the middle Amazon. *Amazoniana: Limnologia et OecologiaRegionalisSystematisFluminis Amazonas*, 9(4), 511-526.

Araújo-Lima, C. A. R. M., Portugal, L. P. S., & Ferreira, E. G. (1986). Fish–macrophyte relationship in the Anavilhanas archipelago, a black water system in the Central Amazon. *JournalofFishBiology*, 29(1), 1-11.

Santos, M. B. L. D., & Freitas, J. R. D. (1988). Preference of *Biomphalariatenagophila* among macrophytes and their periphytons determined through the degree of attractiveness. *Revista do Instituto de Medicina Tropical de São Paulo*, 30(4), 264-269.

Barbieri, R., & Esteves, F. A. (1991). The chemical composition of some aquatic macrophyte species and implications for the metabolism of a tropical lacustrine ecosystem—Lobo Reservoir, São Paulo, Brazil. *Hydrobiologia*, 213(2), 133-140.

Beyruth, Z. (1992). Aquatic macrophytes from a marginal pond at Embu-Mirim river, S. Paulo, Brazil. *Revista de Saúde Pública*, *26*(4), 272-282.

Do Prado, A. L., Heckman, C. W., & Martins, F. R. (1994). The Seasonal succession of biotic communities in wetlands of the tropical wet-and-dry climatic zone: II. The Aquatic Macrophyte Vegetation in the Pantanal of Mato Grosso, Brazil. *Internationale Revue der gesamtenHydrobiologieundHydrographie*, 79(4), 569-589.

Nogueira, F., Esteves, F.A., &Prast, A. E. (1996). Nitrogen and phosphorus concentration of different structures of the aquatic macrophytes *Eichhornia azurea*Kunth and *Scirpuscubensis*Poepp&Kunth in relation to water level variation in LagoaInfernão (São Paulo, Brazil). *Hydrobiologia*, 328(3), 199-205.

OTHER THEMES STUDIED BY BRAZILIAN LIMNOLOGISTS

Decomposition, methods, macrophyte surveys and interactions

A smaller number of papers focused on macrophyte decomposition, methods, macrophyte surveys, and interactions (Figure S1). Decomposition was the sixth most investigated theme, and the papers approached, for example, which factors interfere in detritus decomposition and how decomposition influences ecosystem properties, like as example, the water chemistry (*e.g.*, Bianchini Jr. & Cunha-Santino 2016; Bottino *et al.* 2019).

Chico's contributions to studies on macrophyte decomposition were pioneer in Brazil. Esteves & Barbieri (1983) were the first researchers to study this issue (see Table S1), describing the chemical changes of the decaying matter of macrophytes. A similar approach was applied in numerous other papers following this first one, particularly from the research group of Dr. Irineu Bianchini Jr. (*e.g.*, Bianchini Jr. *et al.* 2010, 2015, 2016; Bottino *et al.* 2019).

Studies indicated that several abiotic features such as oxygen availability, nutrient concentrations, and temperature are important determinants of the decomposition of macrophytes (Carvalho *et al.* 2005, Passerini *et al.* 2016, Paccagnella *et al.* 2020). The effects of microbiota in macrophyte decomposition dynamics have also been studied in Brazil (Carvalho *et al.* 2015, Albertoni *et al.* 2020).

Macrophyte decomposition results in an intense release of chemical compounds into the aquatic ecosystem. Indeed, descriptions of the released compounds from decomposition were also common among Brazilian papers (Pagioro & Thomaz 1999, Bianchini Jr. *et al.* 2010), which is timely given the potential of macrophyte decomposition to increase greenhouse gas emissions (Cunha-Santino & Bianchini Jr. 2013, Fonseca *et al.* 2017). In this context, it seems that the potential of greenhouse gas emissions depends on environmental features, macrophyte identity and chemical content (Grasset *et al.* 2019).

Decomposition is directly connected with the ecosystem perspectives; therefore, addressing how macrophyte decomposition interacted with human impacts is another interesting approach that can be highlighted. For instance, Nomura *et al.* (2017) evaluated fish physiological responses after the decomposition of macrophytes following herbicide control. Another study investigated whether the decomposition of a native species differed from a similar invasive one (de Castro *et al.* 2015). Relatedly, describing decomposition processes for species with invasive potential may help to investigate their effects on ecosystem functioning (Bianchini Jr. & Cunha-Santino 2016).

Estimates of the number of macrophyte species and species lists in specific regions or ecosystems, here included in the theme "macrophyte surveys", received far less attention than the other themes (Figure S1). However, this small number of papers may be related to the method we used in our survey, which was conducted only in journals indexed in the Web of Science – Clarivate Analytics: this database has few journals with a regional-local focus, where papers about surveys are usually published. Also considering our search string, few studies aimed at investigating new methods applied to macrophytes (in special the use of remote sensing methods, *e.g.*, Novo *et al.* 2002; use of herbicides; *e.g.*, Malaspina *et al.* 2017), how macrophytes interact between them (*e.g.*, competition and facilitation; *e.g.*, Nunes & Camargo 2020, Lycarião & Dantas 2017) and with other organisms (*e.g.*, herbivory; Saulino *et al.* 2018), and reviews (*e.g.*, Padial *et al.* 2008, Rodrigues *et al.* 2016) (Figure S1).

The low number of studies (23) reporting species lists or checklists using previous works helps understanding, for example, why the species accumulation curve for the Northeast region of Brazil did not reach an asymptote (Moura-Júnior & Cotarelli 2019). Within this context, we highlight the importance of floristic surveys for management, conservation and hypothesis-driven studies (as pointed out by Padial *et al.* 2008). Furthermore, mainly short-term surveys (i.e., covering two seasons) were conducted, which might hinder the identification of rare species (Moura-Júnior & Cotarelli 2019). Unfortunately, the recurrent science budget cuts in Brazil (Fernandes *et al.* 2017) limit these types of studies.

The limitation to perform field-based studies could partially be overcome by new methodologies to estimate aquatic macrophytes biomass. The number of studies on this theme is small and seems to be declining over time. Since 2012, for example, there is no study in our survey assessing the use of radar or echosounder to estimate the biomass of aquatic macrophytes.

This might be explained by the increased focus on other aspects of the biodiversity, like for example the functional ecology, redirecting the efforts to characterize the natural communities at a higher level of detail (*e.g.*, leaf length, stem length, etc.) than just biomass. Nonetheless, remote sensing techniques can provide complementary information about the temporal dynamics of the plants over large spatial scales, aiding management decisions (Sartori *et al.* 2011).

Mathematical models to estimate diversity (*e.g.*, Evangelista *et al.* 2009), richness (Melo *et al.* 2007), biomass (Nunes & Camargo 2017) and morphological attributes (*e.g.*, Dibble & Thomaz 2009) have not yet been widely used, according to our survey. The use of these methods should be more encouraged, owing to their applicability in experiments (Nunes & Camargo 2017) and in studies aiming to assess the relationships between macrophytes and other biological groups. For example, Dibble & Thomaz (2009) found a positive correlation between fractal dimension (a proxy for morphological complexity) and macroinvertebrate density.

Among the investigations we found, there were also comparisons and assessments of the different methods to remove and control the biomass of aquatic macrophytes. Specifically, studies were focused on mechanical (*e.g.*, Corrêa *et al.* 2005, Scheer *et al.* 2016) and biological control (using grass carp and snails) of invasive (Cruz *et al.* 2015) and native species (Silva *et al.* 2014). Despite the potential advantages of biological control (Domingues *et al.* 2017), we caution that it usually employs non-native species, and thus, this type of method may contribute to new invasions.

Our survey found an increasing number of studies incorporating and testing fundamental ecological concepts. Recent studies have highlighted, for example, the role of environmental dynamics (*e.g.*, seasonality and water levels; Lycarião & Dantas 2017, Murillo *et al.* 2019), climate change (Liu *et al.* 2018), invasive species (Saulino *et al.* 2018) and priority effects in modulating species interactions (Evangelista *et al.* 2017, Nunes & Camargo 2020). We also found studies on the effect of aquatic macrophytes on controlling phytoplankton and cyanobacterial growth (Amorim *et al.* 2019, Amorim & Moura 2020).

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