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FROM THE FLOOD PULSE CONCEPT TO CLIMATE CHANGE, AN ANALYSIS OF THE RESEARCH ON LIMNOLOGY IN THE BRAZILIAN PANTANAL WETLAND

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Abstract: The aim of this work was to evaluate the gaps, trends and advances in the uses of the concepts of flood pulse and climate change through the analysis of scientometrics in Limnology in the Pantanal, between the years 1990 to 2021. The most studied ecological groups and rivers were: aquatic macrophytes and phytoplankton, and Cuiabá and Paraguai, respectively, with the highest number of article publications between 2016-2020. The temporal dynamics of social networks showed the presence of new local institutions, from other Brazilian and international states in the last 20 years. Studies on climate change are still incipient, while those related to the flood pulse are more frequent in the Pantanal. Trends and advances were found in the ecosystem approach of the flood pulse, related to the height of the water level. Few studies address the flood pulse in terms of duration and frequency. The flood pulse is shown as a consolidated concept, emerging as a highly sensitive tool in the face of short, medium and long-term environmental changes, such as climate change, making it possible to identify and deal with socio-environmental challenges and point out participatory governance mechanisms.

Keywords: ecosystem services; Pantanal conservation; scientometrics.

INTRODUCTION

The Pantanal is the largest continuous wetland of the world, encompassing three countries (Brazil, Paraguay and Bolivia). The Brazilian Pantanal has important recognition, receiving the title of National Heritage site (by the Brazilian Constitution of 1988), World Heritage Site, and Biosphere Reserve (both assigned by UNESCO).

In this waterscape, the dominant ecological factor is the flood pulse, an annual water cycle that regulates the ecosystem structure and function. The flood pulse concept began to be investigated in ecology based on the assumption that pulse-driven systems are the most productive. The concept of the "pulse" was first published by Odum (1969) as "Pulse Stability". The flood pulse results in well-defined periods of low water followed by the expansion of rivers at the time of floods and floods that sustain high productivity growth in the aquatic-terrestrial transition zone (Junk *et al.* 1989). The dominant seasonal pattern within the concept of flood pulse indicates that the predictable fluctuation of a river's level reflects the differences in annual precipitation. This concept was also applicable for all wetlands (Junk *et al.* 2011, Junk & Da Silva 1995, 1999, Da Silva & Esteves 1995).

Considering the importance of quantitative rainfall and its distribution across the hydrographic basin, the effects of climate change have begun to be a reference for studies in the Pantanal since the publication of the results of the IPCC (Intergovernmental Panel on Climatic Changes). Christensen *et al.* (2007) simulated changes in precipitation, from 1980 to 1999 and from 2080 to 2099.

Some researchers have shown impacts of global climate change on rainfall in the Amazon, which would reach the Pantanal (Marengo *et al.* 2020, Debortoli *et al.* 2015, Davidson *et al.* 2012), consequently changing the dynamics of the flood pulse (Marengo *et al.* 2020, Lazaro *et al.* 2020, Da Silva *et al.* 2014, 2016). Studies published by a Brazilian climate network showed that the whole country has faced extreme climatic events in the past 10 years (Araújo *et al.* 2019).

Regardless of research scales, the flood pulse concept and its annual or multiannual dynamics have been used to mark studies in the Pantanal. In this context, this research proposes to identify and analyze the current status of the flood pulse and climate change concepts in limnological studies in the Brazilian Pantanal, seeking to answer questions such as which, where, how, and when the concepts were used in limnology. From this investigation, we seek to identify gaps, advances, and trends in the field, thus contributing to building a basis for the implementation of a governance platform in the context of public polices, in the Pantanal in times of climate emergencies.

MATERIAL AND METHODS

Study area

The Pantanal is an immense alluvial plain in the Upper Paraguay River Basin, located at a latitude between 15º30'36" and 22º30'40" S and longitude between 54º45'04" and 58º30'56" W (Silva & Abdon 1998) (Figure 1). This wetland encompasses the territories of Brazil, Bolivia, and Paraguay in an area of 496,000 km^2. Of these, 396,800 km^2 belong to Brazil (61.06%), while the remaining area of 99,200 km^2 is in Bolivia (20.39%) and Paraguay (18.55%) (Brasil 2006, Mourão *et al.* 2013).

The climate in the Pantanal region is classified as Aw-Tropical type, with dry winter, and alternation between dry and rainy seasons, imposing a seasonal character (Kottek *et al.* 2006, Köppen & Geiger 1928). The Pantanal presents a monomodal flood pulse, caused by the well-defined variation of the wet and dry seasons, which regulates its ecological processes (Junk *et al.* 2011, Da Silva & Girard 2004).

Scientometric research is defined by UNESCO and the Organization for Economic Cooperation and Development (OECD) as a quantitative method used to research scientific production through the frequency of articles and citations in indexed databases and impact factor of journals, which allows measuring the amount and impact of scientific publications, in addition to analyzing their interrelationships (Spinak 1998). Scientometrics has made possible to analyze the status of various themes and areas of knowledge.

The database was made in the Repositories SciELO, Scopus, Google Scholar and Science Direct, accessed on the journals portal of the Coordination for the Improvement of Higher Education Personnel (CAPES). This database classifies articles in the concepts of A (A1, A2, A3), B (B1, B2, B3, B4) and C. The search filters used were: flood pulse, limnology, Paraguay River, Pantanal, climate change and biodiversity. The analysis assessed the concepts present in the title, abstract, and keywords, between 1990 and 2021. The first list of 3,452 articles were reduced to 91 articles after applying filters.

We also evaluated the scientific production of the 15 researchers selected according to their production within the theme of Limnology and their respective institutions stored in the Lattes Platform of the National Council for Scientific and Technological Development (CNPq) that included scientific articles outside the indexed databases, books, and chapters published during the same period. In that base we elaborate the social network where each author was represented

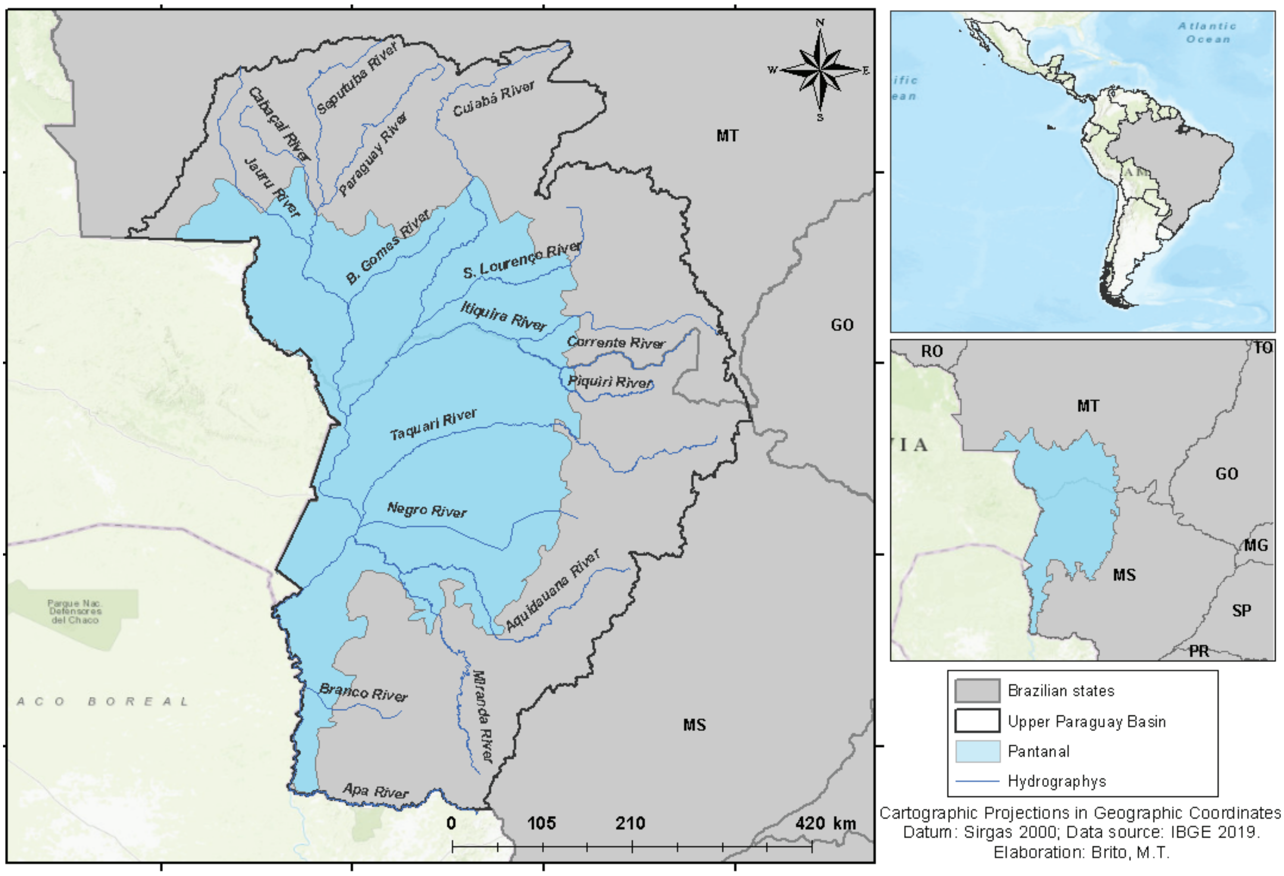

Figure 1. Study area (Brazilian Pantanal) in Brazil and South America.

by a circle (vertex/node) whose size reflects the number of publications.

RESULTS

The 91 selected articles were published in 62 journals between 1990 and 2021, among which 49% were indexed in Science Direct (SD), 34% in Scopus (SCO), 10% in Scielo (SCI), and 7% in Google Scholar (GS). The largest number of publications was identified in the journals Science of the Total Environment (Qualis A1) and Acta Limnologica Brasiliensia (Qualis B1) (Figure 2). The high numbers of publications were recorded in the years 2011-2020 (55%), and of the institutions involved was larger in the years 2016-2020 (35%) (Figure 3).

In order to analyze the frequency of concepts related to the flood pulse, the most cited keywords were counted to elaborate the cloud words using the online software Wordcloud. The main keywords identified in the scientometric research were: Flood pulse, Pantanal and Limnology, followed by other eight words (Figure 4).

Of the total number of articles analyzed, 37 articles worked with other fields of limnology and 54 articles showed ten ecological groups: aquatic macrophytes had 30 articles; phytoplankton 12 articles; zooplankton 8 articles; and periphyton 4 articles. Publications on these four groups involved 22 research institutions. The main institutions were the Federal University of Mato Grosso (UFMT), the Federal University of Mato Grosso do Sul (UFMS), the Federal University of Rio de Janeiro (UFRJ) and the Federal University of São Carlos (UFSCar) (Figure 5). The number of publications distributed by sub-basins was higher in the Cuiabá River, followed by the Paraguay River and Taquari River Basin (Figure 6).

The municipality of Corumbá had the largest number of publications and it involved studies conducted in the Paraguay and Taquari rivers by Embrapa Pantanal, UNESP, and UFMS. The municipalities of Barão de Melgaço and Cáceres followed in the second and third positions, respectively, and are studied mainly by UFMT and UNEMAT (Figure 7). The network nodes showed that some researchers were more concentrated in the central region and others, dispersed and isolated, mainly in peripheral areas. The interaction between researchers also reproduces local connections characterized by those that stay more in the central area (Figure 8).

The nodes that represent researchers in the central region are the largest and more intertwined (blue color, Figure 9). However, few of them remain in the same position currently. Some were members of a long-term international cooperation project that finished and others are retired so that they are not currently part of the local network. On the other hand, in the

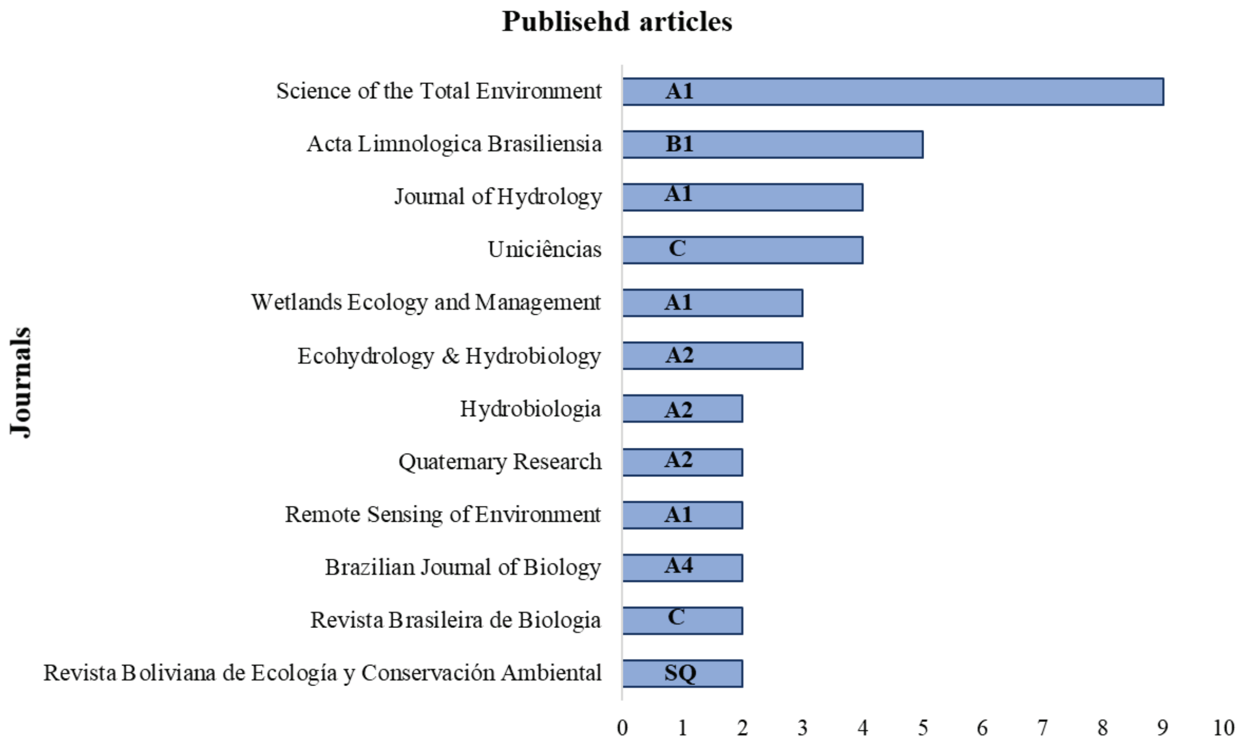

Figure 2. Number of articles published in the main journals documented (Qualis CAPES/ 2017-2020) and registered in search databases SD, SCO, SCI, GS (1990-2021).

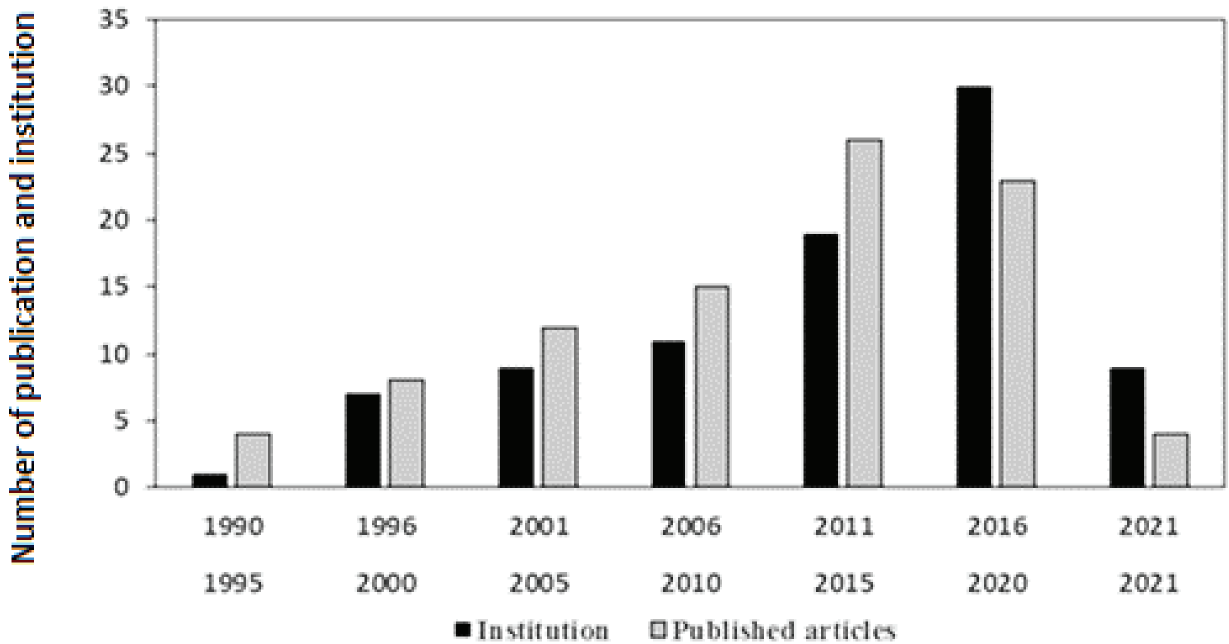

Figure 3. Number of publications and institutions involved on database SD, SCO, SCI, GS (1990-2021).

Figure 4. Cloud of keywords grouped from the databases SD, SCO, SCI, GS (1990-2021).

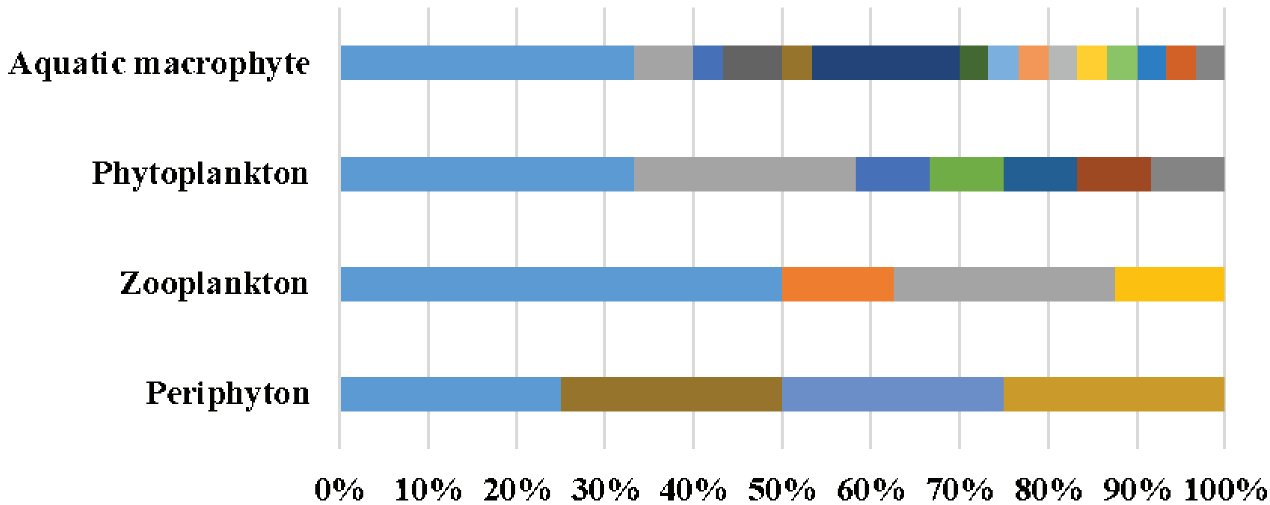

Figure 5. Contribution of each research institution to the total number of publications according to the ecological group, between 1990 and 2021. Caption: Universidade Federal de Mato Grosso; Universidade Federal do Rio Grande do Sul; Universidade Federal do Rio de Janeiro; Universidade do Estado do Rio de Janeiro; Embrapa Pantanal; Instituto de Botânica de São Paulo; Universidade Federal de Juiz de Fora; Universidade Federal do Paraná; Universidade Federal de São Carlos; Universidade do Estado de Mato Grosso; Universidade Federal de Mato Grosso do Sul; Universidade Federal de Minas Gerais; Universidade Federal de Viçosa; Universidade Estadual de Campinas; Universidade Estadual de Mato Grosso do Sul; Institute of Earth Sciences; Department of Envermonty Chemistry; Syke Institute; Penn State University; University of Kentucky; Universidade da República; Institute of Environmental Assessment and Water Research.

peripheral position, new groups (green color) appear in ascending position (Figure 9).

The temporal dimension of studies on Limnology in the Pantanal Wetland showed that, from the beginning of the 1990s to 2000, the Brazilian agreement between UFMT and the Max Planck Institute of Limnology facilitated an increase in the number of publications. A similar partnership occurred between Embrapa Pantanal and Michigan University. The more recent emergence of other universities publishing on Limnology can also be seen (Figure 10).

The number of Pantanal-related limnology publications focusing on climate change is increasing in recent years. This increase occurs mainly in article format, with a decrease in books

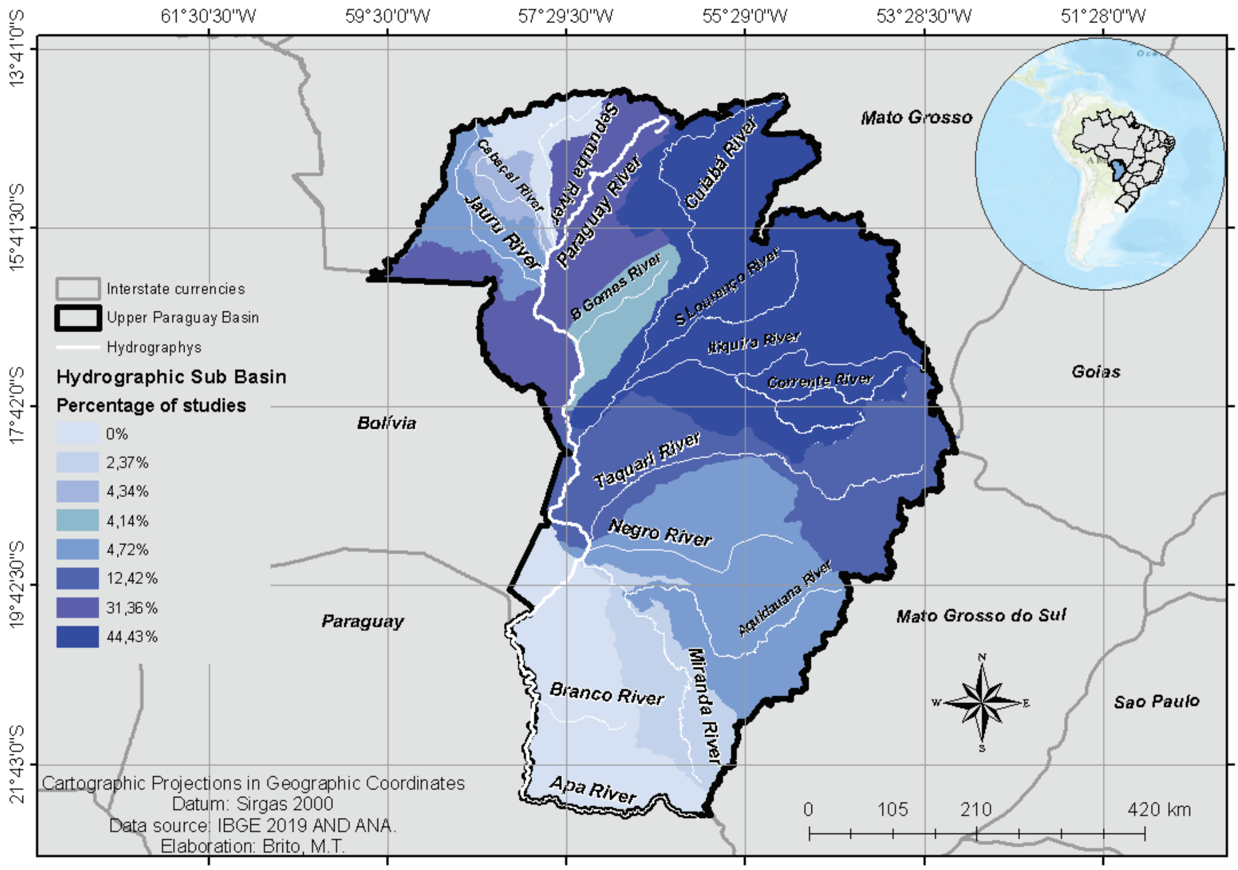

Figure 6. Percentage of studies published in periodicals obtained in scientometric databases plus books, chapters, and articles from the CNPq Curriculum Lattes Platform, distributed by river sub-basin in the Paraguay River basin.

(Figure 11). In the past 20 years of research, there were 24 articles in the region, 16% of which were published as books, 34% as book chapters, and 50% as articles, all of which studied, directly or indirectly, the Pantanal biome.

DISCUSSION

Since the application of the concept of flood pulse and the definition of the ATTZ (Aquatic Terrestrial Transition Zone) in the studies of the great tropical floodplains (Junk *et al.* 1989) and its application in the Pantanal (Junk & Da Silva 1995, 1999, Junk *et al.* 2011), there have been advances with different ecological groups and research approaches. This study allowed us to know the extent and better understand the nature of the research on limnology of the Brazilian Pantanal developed in the last three decades that focused on the concept of the flood pulse and, more recently, on climate change.

The concept of flood pulse was consistent in the publications identified in scientometric research, however, concerning climate change, studies are still incipient. Regarding the use of the flood pulse concept in the Pantanal, bibliographic production increased considerably in the last years with publications in journals of CAPES (A1).

The highlight of the group of aquatic macrophytes is related to pioneering research that was carried out by Da Silva & Esteves (1993, 1995) and Da Silva *et al.* (1994) on limnological characteristics, biomass and nutrient accumulation, in the parental baías of Cuiabá River, in the municipalities of Santo Antônio de Leverger and Barão de Melgaço; primary productivity of aquatic macrophytes in the flooded fields of the Bento Gomes River in the municipality of Poconé (Penha *et al.* 1999, 1998).

Later, research identified studies in the Cuiabá River that showed the positive interaction between horizontal expansion and biomass accumulation in aquatic macrophytes with the amplitude of the flood pulse and temperature stability with lower daily variation in the rainy and full seasons (Nunes & Da Silva 2021, Bleich *et al.* 2009, Abdo

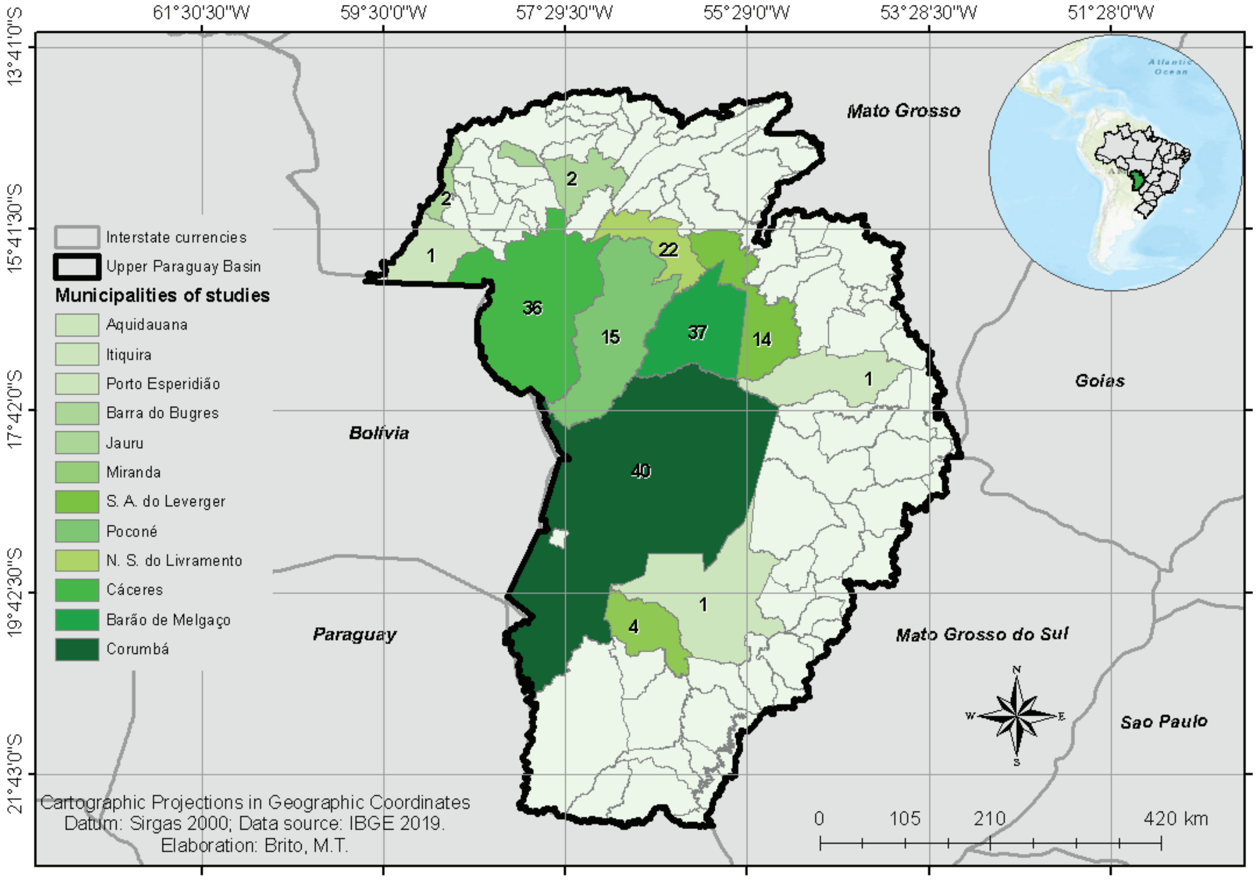

Figure 7. Numbers of studies published in periodicals obtained in Scientometric databases plus books, chapters, and articles from the CNPq Curriculum Lattes Platform, distributed by Pantanal Municipalities.

& Da Silva 2004). The supply of habitats and the influence on environmental heterogeneity by aquatic macrophyte communities, mainly for fishes, were assessed in the Caiçara baía of the Paraguay River (Pains da Silva *et al.* 2010), in the Chacororé-Sinhá Mariana lake system of the Cuiaba River (Pacheco & Da Silva 2009), and the southern Pantanal region (Leuchtenberger *et al.* 2020; Saulino & Trivinho-Strixino 2014).

More recent studies with aquatic macrophytes address the richness, beta diversity associated with the hydrological connectivity pattern, dispersion strategy, and establishment related to the flood pulse in the municipality of Corumbá (Catian *et al.* 2021, Coutinho *et al.* 2018, Catian *et al.* 2018). The invasion of aquatic grass species was also recorded and associated with the seasonal pattern of the flood pulse (Bao *et al.* 2020).

In the first time research with phytoplankton was related with only taxonomic and species composition studies. Nowadays the research with phytoplankton advances in habitat variety, community structure, current studies approach and functional groups. The variety of environments studied diversified from unique geomicrobiological systems that harbor extremophilic cyanobacteria (Guerreiro *et al.* 2019) to those lakes, which alternate the dominance of phytoplankton and aquatic macrophytes as a function of the flood pulse (Loverde-Oliveira *et al.* 2009). Phytoplankton studies included new records of taxa (Santos & Sant'anna 2010, Loverde-Oliveira *et al.* 2011); ecological functions and patterns of variation of the phytoplankton, zooplankton and periphytic community (Loverde-Oliveira *et al.* 2019, Branco *et al.* 2018, Fantin-Cruz *et al.* 2011); structuring dynamics related to the flood pulse and functional connectivity (Nardelli *et al.* 2021, Loverde-Oliveira *et al.* 2013, Lima *et al.* 2012, Loverde-Oliveira & Huszar 2007, Oliveira & Calheiros 2000). Knowledge about periphyton has been

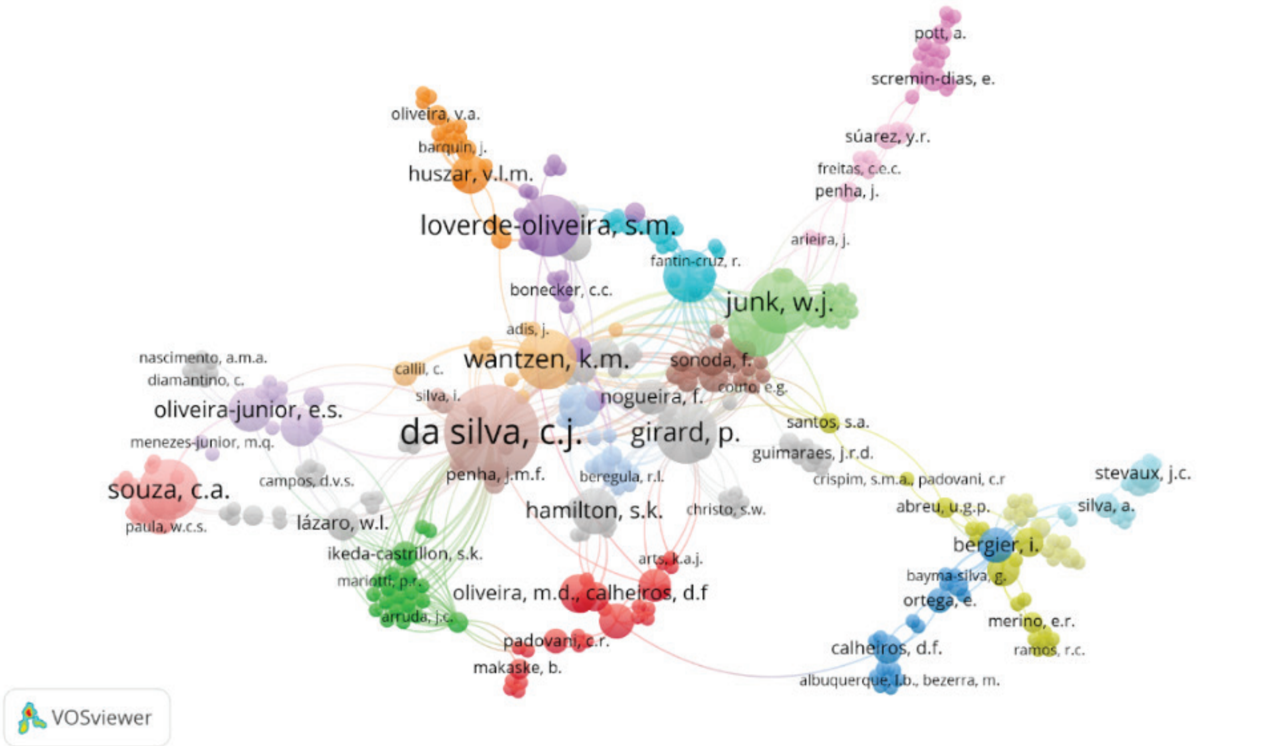

Figure 8. Network of researchers on Limnology in the Pantanal Wetland from scientometric databases plus books, chapters and articles from the CNPq Curriculum Lattes Platform CV Lattes.

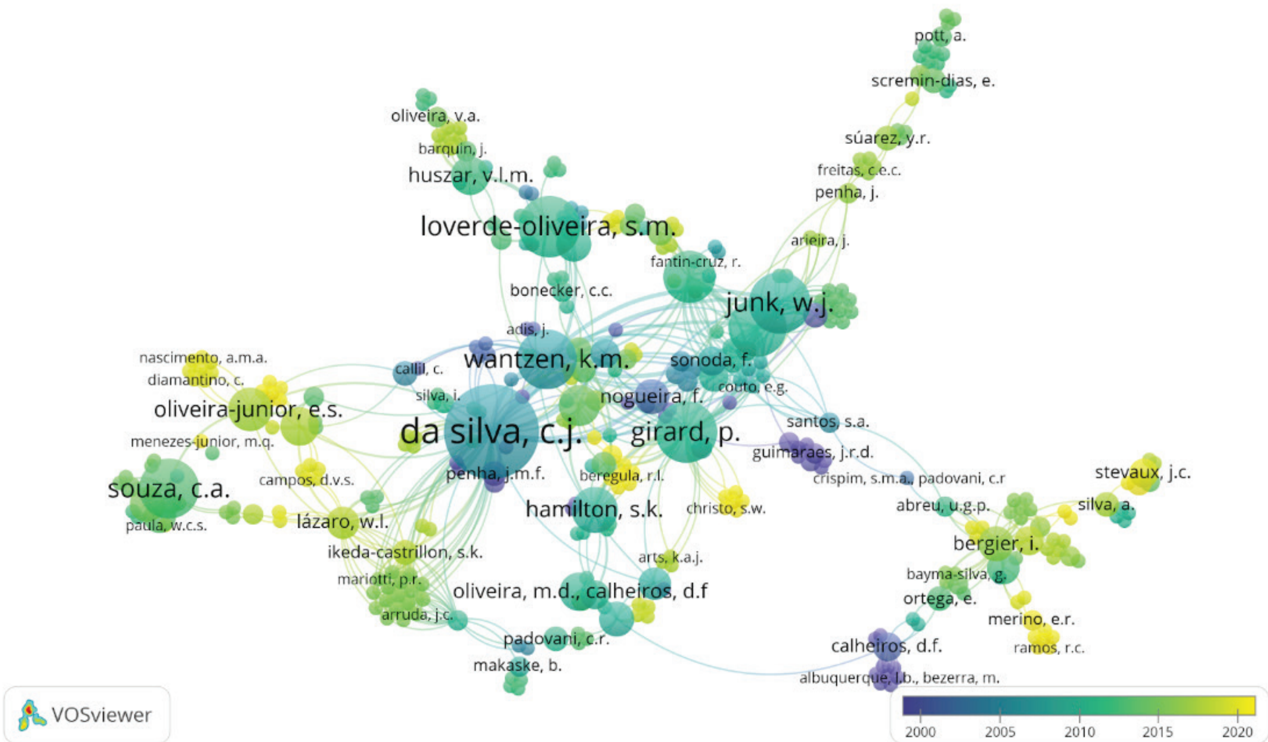

Figure 9. Temporal dimension of the network between researchers of Limnology in the Pantanal Wetland from scientometric databases plus books, chapters, and articles from the CNPq Curriculum Lattes Platform.

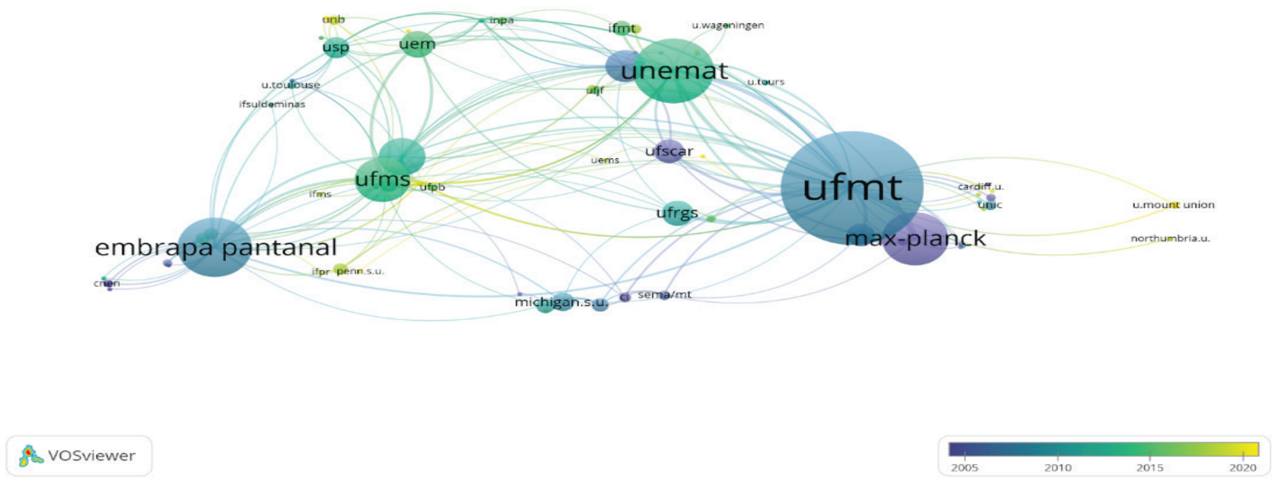

Figure 10. Temporal dimension of the network between institutions researching limnology in the Pantanal Wetland (concerning the flood pulse concept), from scientometric databases plus books, chapters, and articles from the CNPq Curriculum Lattes Platform.

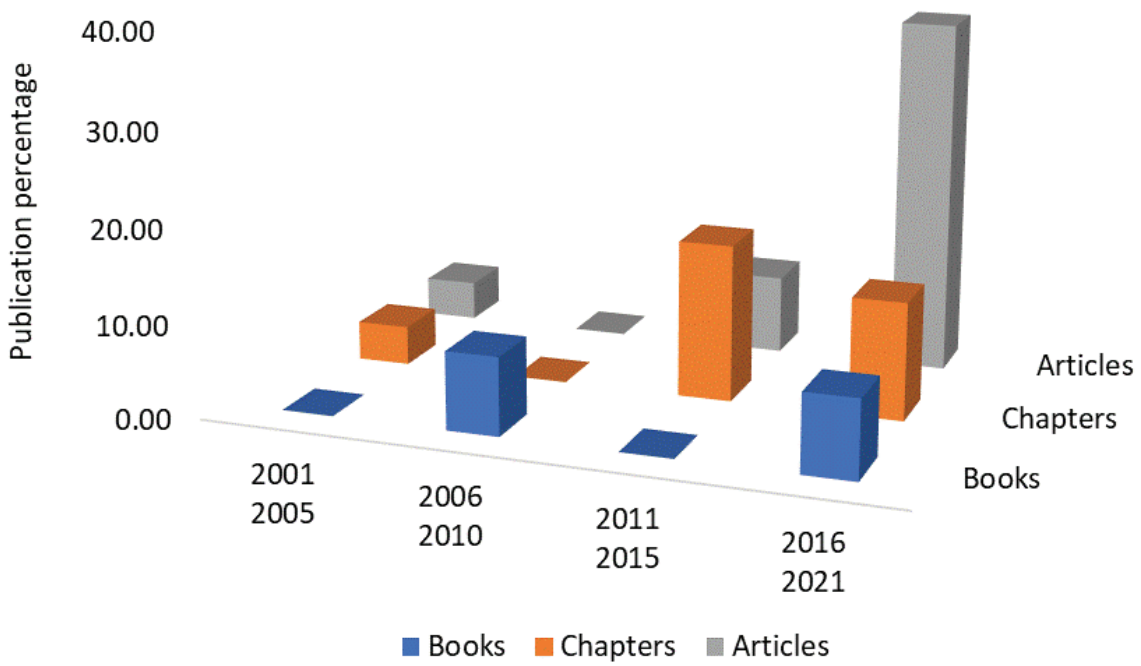

Figure 11. Percentage of published articles, chapters, and books on limnology research focused on climate change in the Pantanal from 2001 to 2021.

evidenced in the production of methylmercury by cyanobacteria in the Paraguay River (Lazaro *et al.* 2013, 2018).

Ecological processes of nutrient cycling and flood pulse that cause anoxia in the aquatic system, a phenomenon known as *diquada* or *decoada*, have been studied as traditional ecological knowledge (Da Silva 1984), its ecological causes and effects (Calheiros *et al.* 2018, Andrade *et al.* 2015). The impacts of this ecological process may have its dimensions expanded due to large nutrient intake caused by inadequate activities in the flooded areas of the Pantanal and the Paraguay River Basin as a whole (Hamilton *et al.* 1997).

In terms of advances and trends, this research identified nine articles related to the conceptual framework of ecosystem services, which was adopted by the Millennium Ecosystems Assessment (MEA 2005), a document made by the United Nations aiming "to assess the consequences of ecosystem change on human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being". The MA framework includes regulation services related to climate change, flood pulse and water purification; provisioning services for food, water, timber, and fiber; supporting services related to soil formation, photosynthesis, and nutrient cycling that maintain the conditions for life and cultural services..

The Pantanal wetland is characterized by the flood pulse that represents the more important regulating ecosystem service operating on resiliency and adaptations of the Pantanal biome (Da Silva & Moura 2012). In terms of cultural ecosystem services, Groot *et al.* (2010) and Daniel *et al.* (2012) used similar categories to distinguish them: landscape aesthetic (inspirational services), cultural landscapes (cultural heritage, cultural identity, and spiritual significance), recreation, and tourism. In this sense, Da Silva & Silva (1995) identified many elements with spiritual value in the systems of the "baías" Cachororé and Sinha Mariana of Pantanal; corroborate by Leite (2003) in his book "Chacororé's enchanted waters: nature, culture, landscapes, and myths of Pantanal".

Other categories of the cultural ecosystem services were identified: as having ecotourism value (Da Silva & Moura 2012); and educational importance (Spanholi *et al.* 2020). According to Chan *et al.* (2012), cultural ecosystem services are the "great green hope" and the new civilizational effort, which has to bring the ecological dimension of the economy to the context of sustainability.

The advances identified in scientific production are the result of improvements in the structure of regional institutions, consolidation of Graduate Programs and international partnerships. Cooperation that stood out was that of the UFMT with the former Max Planck Institute of Limnology of Plon, Germany, between 1991-2005, through the Pantanal Ecology Project (Wantzen *et al.* 2011, Junk *et al.* 2011).

Additionally, international partnerships occurred between Embrapa and the California and Michigan Universities (Hamilton *et al.* 1997; Oliveira *et al.* 2019); Wageningen University in the Netherlands with Embrapa (Jongman *et al.* 2005); Research Center in Limnology, Biodiversity, and Ethnobiology of the Pantanal (UNEMAT) with Institute of Environmental Assessment and Water Studies - IDAEA, Spain (Lazaro *et al.* 2019, 2013). Also, national institutions emerged in the scientific scenario in the Pantanal, such as the State University of São Paulo, associated with the UFMS and Embrapa Pantanal; UNEMAT with the UFSCar (Abdo & Da Silva 2012) and with UFRJ (Lazaro *et al.* 2018).

The growth of publications is associated with increase of investment in infrastructure, the emergence of new graduate programs, and/or new research groups reported in the CNPq (Coutinho *et al.* 2012, CAPES, 2021). In this context, we highlight the national support of MCTI in the international cooperation that occurred in the past and CNPq in the development of limnological research, within the scope of the Long-Term Ecological Research - PELD/CNPq, in which four sites have already been implemented and are coordinated by UFMT, EMBRAPA Pantanal (before 2015), UNEMAT (2016-2024) and UFMS (2020-2024).

In relation to climate change, this research showed that publications on this topic are still incipient for the Pantanal (Marengo 2015; Marengo *et al.* 2021), with a tendency to temporal displacement of rainfall and a reduction in the volume of precipitation with a direct effect on the flood pulse, mainly in terms of amplitude, duration and, consequently, its lateral connectivity and extensions. The first studies related to climatic change in the Pantanal analyzed the large drought during the end of the 1960s and the beginning of the 1970s, as well as the start of the large flooding cycle in the Paraguay River (Collischon *et al.* 2001).

Only after Intergovernmental Panel Studies indicated the increase of temperature and decrease of rain for the Pantanal region, studies such as that of Debortoli *et al.* (2015), highlighted the temporal displacement of rain from the Amazon Rainforest to the Pantanal region and indicated reduced rainfall for some localities. Studies published between 2005 and 2015 called attention to climatic changes in Brazilian biomes, including the Pantanal (Irigaray *et al.* 2011). The perception of climatic change by Pantanal traditional communities was recorded, underlining the vulnerability of these native social groups (Da Silva *et al.* 2016, Da Silva *et al.* 2014).

As a consequence of these variations in rainfall predict a reduction of 10% to 20% between 2010 and 2040 (Marengo 2015) were register a decrease of water volume of 16% in the last 20 years in the Paraguay River (Lázaro *et al.* 2020). The effect of the severe drought of 2020 and 2021 on Pantanal and its surroundings, caused hydric stress on vegetation and favored the fires in the Pantanal in 2020 (Marengo *et al.* 2021).

The main impact on the flood pulse in the Pantanal wetland is the energy policy matrix based on the hydroelectric energy source (Calheiros *et al.* 2018, Da Silva *et al.* 2015, Zeilhofer & Moura 2009). To assess these socio-environment impacts on the Pantanal wetland, the ANA - Brazilian National Water Agency (2017) commissioned studies that involved the Pantanal Scientific Institution and other Brazilian institutions, including more than 50 researchers, to investigate the impact of the hydroelectric power plants on the Pantanal (Jardim *et al.* 2020, Ely *et al.* 2020, Oliveira *et al.* 2020).

Another impact of climate change that contributed to the extreme drought in 2020 was the reduction in about 60% of the size of the famous system of the lakes Chacororé and Sinhá Mariana in the Pantanal wetland. This event, also was associated with the Manso dam upstream that controls the flood pulse in Cuiabá River and water volume to reach the lake (Da Silva *et al.* 2021).

Beside to the energy and agricultural/livestock drivers (Tomas *et al.* 2019, Da Silva *et al.* 2015), a new impact appears due to a transport policy that plans to build three shipping ports (called waterway project) in the Paraguay river, downstream from the city of Caceres and upstream from the Taiamã Ecological Station. The management of the Pantanal needs to be connected with the Sustainable Development Agenda, especially in times of climate change, as the system presented extreme droughts in the last two years (2020-2021). This project affects a main biocultural corridor that includes five Protected Areas: Jubran Private Reserve, Guirá Mato Grosso State Park, Indigenous Land Guato, Taiamã Ecological Station and Pantanal National Park, this last one are nuclear areas of the Pantanal Biosphere Reserve and Ramsar Sites.

The public policies followed a disconnected path, without integrating a sustainability approach to analyze all impacts together, which would favor decision making that promotes a more sustainable alternative (Tomas *et al.* 2019, Da Silva *et al.* 2015), related to the efforts of the public policy wetlands definition and its implementations (Junk *et al.* 2018). The energetic matrix based on hydric power can be suspended in the Pantanal, since it corresponds to lower contribution to the energy integrated system, and can be replaced by solar energy, to reach the objectives of sustainable development, goal 13 related to climate change.

Our study showed advances in limnological researches on amplitude attributes of the flood pulse concept caused by increase in the number of researchers, scientific institutions, international cooperation, and qualification of new researchers by local graduate programs. On the other hand, we observed some gaps on the level of studies and cover area; which demands research of genetic diversity, population, and largest scales, such as landscapes, as well as their relationship with land and water use, and studies with duration and frequency attributes of flood pulse.

New international partnerships are necessary to investigate climate changes and bring this approach to local institutions; this strategy can reduce gaps and promote advances. At national level it's necessary to maintain and increase the investment, for example, to the PELD/CNPq, to guarantee the tendency of scientific production growth, formation of human resource and to contribute for decision-making that favor the conservation of the Pantanal wetland.

CONCLUSION

This study showed an overview of limnology research in the Pantanal wetland over the last 30 years, identifying advances and establishment of the flood pulse concept in all publications of local institutions and universities. The climate changes studies in the Pantanal are still incipient, although the baseline of this knowledge is in process.

Regarding the current approach of the ecological groups, the list needs to be increased for phytoplankton, zooplankton and macroinvertebrates for example. The publications have pointed out the gaps and significant advances and reinforce the need to expand studies on composition, functional diversity, changes and ecological mechanisms for adaptation to climate variability.

Research should also focus on the effects of land and water use in the Pantanal wetland plains and upstream areas, with a multi-scale look to improve our understanding of ecosystem structure, function and change. New research should be designed to expand the knowledge on ecological patterns related to the flood pulse and climate change as umbrella subjects to maintain water, biological conservation, and social diversity in the Pantanal wetland.

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