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Sustainability Agenda for the Pantanal Wetland: Perspectives on a Collaborative Interface for Science, Policy, and Decision-Making

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Abstract

Building bridges between environmental and political agendas is essential nowadays in face of the increasing human pressure on natural environments, including wetlands. Wetlands provide critical ecosystem services for humanity and can generate a considerable direct or indirect income to the local communities. To meet many of the sustainable development goals, we need to move our trajectory from the current environmental destructive development to a wiser wetland use. The current article contain a proposed agenda for the Pantanal aiming the improvement of public policy for conservation in the Pantanal, one of the largest, most diverse, and continuous inland wetland in the world. We suggest and discuss a list of 11 essential interfaces between science, policy, and development in region linked to the proposed agenda. We believe that a functional science network can booster the collaborative capability to generate creative ideas and solutions to address the big challenges faced by the Pantanal wetland.

Keywords

Pantanal, sustainability, wetlands, biodiversity, education, development

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Introduction

Improving the integration of science into policy-making has been key to advancing science-based, environmentally sound and sustainable development globally (Ascher, Steelman, & Healy, 2010). Scientists and citizens have increasingly been working in large collaborative networks to achieve science-based policy-making. High-profile examples at the global level include the United Nations Intergovernmental Panel on Climate Change, the Sustainable Development Goals for 2030 (United Nations, 2015), and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (https://www.ipbes.net/; but see Koetz, Farrell, & Bridgewater, 2012). These working groups continue to play a fundamental role in tackling global challenges (United Nations, 2015). Concurrently, scientists are increasingly engaged in translating their research into policy recommendation in efforts to address the greatest environmental challenges of the 21st century such as species mass extinctions, climate change, and deforestation. A recent example is the article "World Scientists' Warning to Humanity: A Second Notice" (Ripple et al., 2017), a rallying call to policy makers by more than 1,500 scientists from 184 countries. Ripple et al. (2017) appeal for initiatives to limit population growth and to drastically diminish per capita consumption of fossil fuels, meat, and other resources. The article found wide resonance across a wide range of environmental sciences, including wetland scientists (Finlayson et al., 2018).

Unfortunately, socioecological systems (i.e., people and places) and institutional arrangements (e.g., UN, EU, national, regional, and local governments) adapt to and resist changes in policies and practices (Karam-Gemael, Loyola, Penha, & Izzo, 2018; Kayal, Lewis, Ballard, & Kayal, 2018; Ostrom, 1990; Rose, 2015; Rossetto & Tocantins, 2015). Overcoming such resistance and allowing for the development and implementation of sustainable development, requires democratic stability, political engagement by an educated public, and science-informed policy (Dobrovolski et al., 2018). Part of the problem has always been the difficulty of scientists to engage a broader public in complex questions and research. Over the past few decades, new approaches such as citizen science have played a critical role in creating both an educated and politically engaged public and informing environmental policy (Dillon, Stevenson, & Wals, 2016). However, with the expansion of citizen science came the recognition that science needs to be relevant to all stakeholders and needs to be cocreated by all stakeholders. Civic science intends to do this, by integrating scientists as one of the stakeholders in a community-driven process of joint learning (Dillon et al., 2016). Given the world's current situation, characterized by complexity and contradictions (Colloff et al., 2017), rising political populism, and increasing human pressure on natural environments, it is imperative that we expand such efforts and build bridges between science and environmental agendas. In doing so, the conservation of natural areas (e.g., forests, savannas, wetlands) could be part of a more comprehensive strategy aimed to reconcile human activities and biodiversity conservation.

In May 2018, a group of scientists, educators, nongovernmental organizations (NGOs), research institutions, landowners, and other stakeholder met to discuss how their work could be better linked to policies influencing biodiversity conservation and sustainable development in the Pantanal. The Pantanal is one of the largest, most diverse, and continuous inland wetland in the world (Harris et al., 2005) and has been classified by Costanza et al. (1997) as one of the main hotspots for ecosystem services worldwide. Wetlands, such as the Pantanal, provide critical ecosystem services both globally and locally, such as the maintenance of regional microclimates, regulation of river discharge, fishing, water security, native pasture, habitat for threatened species, and wintering ground for migratory species (e.g., Clarkson, Ausseil, & Gerbeaux, 2013; Mitsch, Bernal, & Hernandez, 2015; Nunes & Tomas, 2008; Turpie, Lannas, Scovronick, Louw, & Malan, 2010; Zedler & Kercher, 2005). Yet, wetland ecosystems have been subjected to heavy human-induced impacts. Since 1900, between 54% and 80% of all inland wetlands have lost their ecological functions (Davidson, 2014; Van Asselen, Verburg, Vermaat, & Janse, 2013).

The group identified many ongoing threats as well as many ongoing initiatives for addressing these threats. However, only few efforts seem to actually have found their way into decision-making, policies, laws, and practices. To address this issue, we developed this article, in which we aim to analyze the conservation context in the Pantanal and synthesize the challenges, trends, and opportunities for the promotion of sustainability in the region. This collective stakeholder effort aims to (a) outline current science and policy issues, (b) identify existing scientific research and data to address the issues, and (c) develop strategies for mainstreaming existing and future science into the policy-making for the Pantanal. Ultimately, the authors hope to highlight the importance of science for informing and developing sustainable-use practices in the Pantanal.

The Pantanal

The Pantanal wetland is located in the center of the Upper Paraguay River Basin in South America encompassing 179,300 km^2 across Brazil (78%), Bolivia (18%), and Paraguay (4%); an area larger than England

(Figure 1; Adámoli, 1981; Mereles et al., 2000; Ministerio de Medio Ambiente y Agua, 2017). In Brazil, Pantanal is located in Mato Grosso (MT; 35%) and Mato Grosso do Sul (MS; 65%) states. Well-defined dry and wet seasons, with rainfall concentrated in the summer (November–March), produce a seasonal flood pulse and monomodal hydrological signature (Junk, Bayley, & Sparks, 1989; Junk & Wantzen, 2004; Penatti, Almeida, Ferreira, Arantes, & Coe, 2015). These seasonal floods influence animal and plant communities, nutrient cycling, and primary productivity (Fischer et al., 2018b; Junk & Cunha, 2005; Junk & Da Silva, 1999). The landscape consists of a mosaic of floodable and nonfloodable grasslands, forests, open woodlands, and temporary or permanent aquatic habitats. The Pantanal supports significant biodiversity with more than 2,000 plant (Pott, Oliveira, Damasceno-Junior, & Silva, 2011), more than 580 bird (Nunes, 2011; Tubelis & Tomas, 2003), 271 fish (Britski, Silimon, & Lopes, 1999; Souza et al., 2017), 174 mammal (Tomas et al., 2010), 131 reptile (Ferreira et al., 2017), and 57 amphibian species (Piva, Caramaschi, & Albuquerque, 2017; Souza et al., 2017; Strüssmann, Ribeiro, Ferreira, & Béda, 2007) and countless invertebrates and microorganisms. Butterflies, for example, may encompass more than 500 species in the floodplain and more than 1,000 species in the Upper Paraguay River Basin (Brown Jr., 1986). It also harbors substantial populations of threatened species such as jaguar (*Panthera onca*), giant otter (*Pteronura brasiliensis*), marsh deer (*Blastocerus dichotomus*), pampas deer (*Ozotoceros bezoarticus*; Mourão et al., 2000; Tomas et al., 2010, 2015), and hyacinth macaw (*Anodorhynchus hyacinthinus*; Guedes, Bianchi, & Barros, 2008).

Most of the Pantanal is held in private lands comprising 93% of the land in the Brazilian side. The existing protected areas network is far from the 17% advocated by the Aichi Goals for terrestrial ecosystems and poorly represents Pantanal biodiversity (for Brazil: Oliveira et al., 2017). For instance, strictly protected areas (International Union for Conservation of Nature [IUCN] Ia and II Categories of protected areas; see Dudley, 2008) cover 14,800 km^2 (5.71%) of the Pantanal wetland (Figure 2, online Appendix 1 and Appendix 2). Private protected areas (Reserva Particular do Patrimônio Natural in Brazil, and Reserva Natural Privada in Paraguay, also IUCN Ia category) are scattered in the Pantanal floodplains, ranging in size from less the 1.00 to 1,174.00 km^2, covering 3,046.53 km^2 (1.7% of the Pantanal). In Brazil, there are two Environmental Protection Areas, yet only one fully within the Pantanal boundaries (basically under the IUCN IV category but often including restrict use categories, such as Ia, Ib, and II); in Bolivia, two of such areas are classified as Integrated Management Natural Areas and comprise 4,528 km^2 (2.9%). Figure 2 indicates the protected areas partial or totally located in the Upper Paraguay River Basin and the Pantanal wetland (see online Appendix 1 and Appendix 2 for the additional information on these protected areas). In addition, two UNESCO Biosphere Reserves exist in the region of the Upper Paraguay River Basin: The Pantanal Biosphere Reserve in Brazil and the Chaco Biosphere Reserve in Paraguay, both containing several different types of protected areas as nuclear zones and management areas. There are seven indigenous lands in the region encompassing $\sim$11,724 km^2 (7.4%), which should be considered as IUCN VI category of protected areas. The data on protected areas presented here are not complete, as data on several private protected areas could not be obtained from federal and state environmental agencies in Brazil. However, we consider the data a good approximation of the status of nature protection in the Pantanal, indicating that the protected area needs at least to triple to achieve the Aichi Goals.

Cattle ranching in the Pantanal started in the 17th century and is now the prevalent economic activity (Machado & Costa, 2018), and it is conducted by approximately 3,000 ranches in the Brazilian side and an unknown number in Bolivia and Paraguay. Cattle graze at relatively low densities averaging from 0.5 to 0.8 heads per hectare in native and cultivated pastures, respectively. Figure 3 represents the variation in the potential density of cattle head per ranch already inscribed and certified in the Cadastro Ambiental Rural (Rural Environmental Cadaster) in the Brazilian side of the Pantanal wetland. Ranches are relatively large, with 36.2% with 5,000 to 10,000 ha, 29.3% with 10,000 to 30,000 ha, 6.1% with 30,000 to 60,000 ha, and 0.7% with more than 60,000 ha. Cattle densities are not uniform, as it depends on the vegetation cover in each property. However, ranches located in higher regions (central and border areas), as well as the ranches mostly modified by the replacement of native vegetation by cultivated pastures, present higher potential cattle densities. The total cattle herd in the Brazilian Pantanal has been estimated as 3.8 million heads, producing approximately 1 million calves per year (Oliveira et al., 2016b).

Fishing continues to be an important social and economic activity, providing subsistence to traditional communities in the Pantanal. Recreational fishing also is the basis for extensive tourism (Barletta et al., 2016; Mateus, Vaz, & Catella, 2011). Sport and amateur fishing associated with this tourism has not led to overfishing, with the exception of the pacu *Piaractus mesopotamicus*, which is the most captured fish species (Barletta et al., 2016; Mateus et al., 2011). Two other species seem to be exploited sustainable way, as stock seem to be kept below its maximum sustainable yield, the catfish

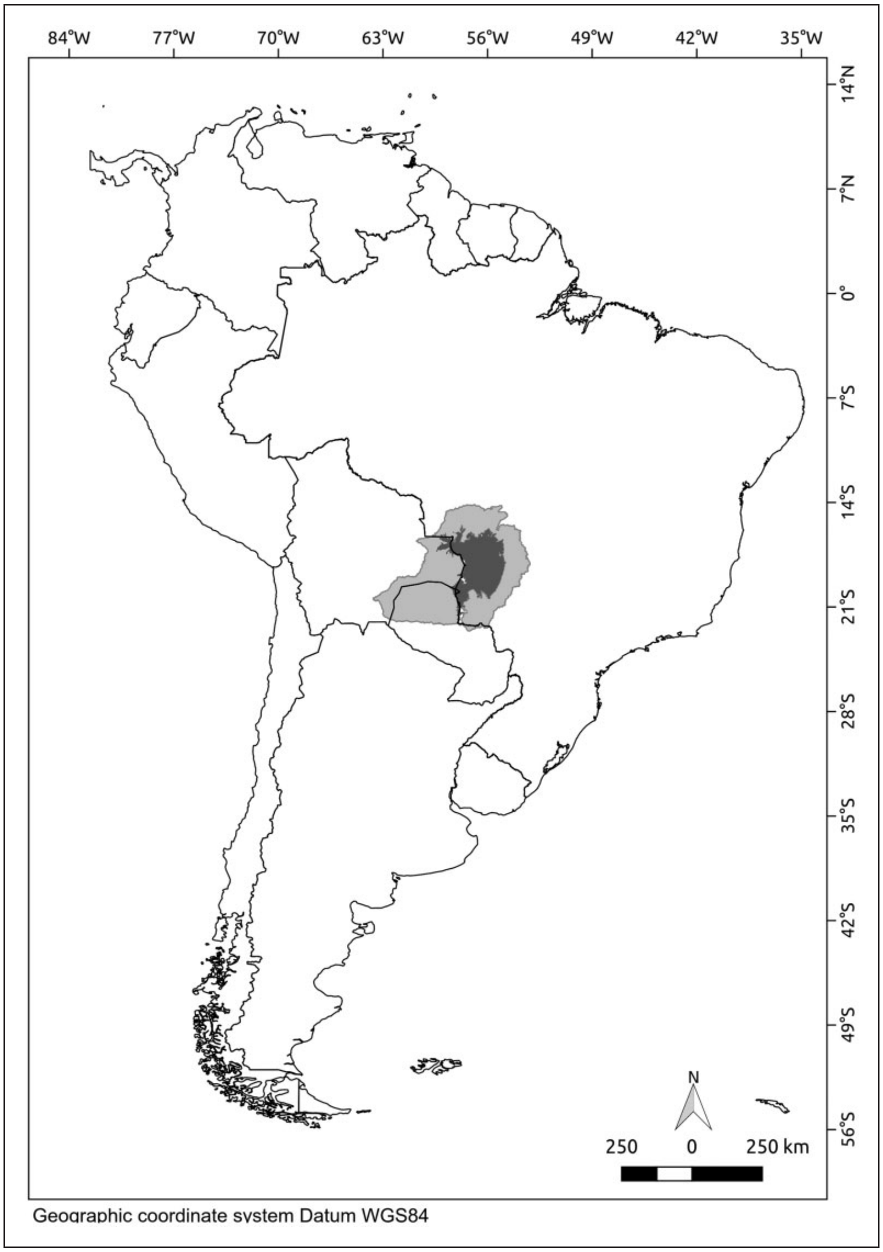

Figure 1. Upper Paraguay River Basin (light gray) and the Pantanal wetland (dark gray) in South America.

Pseudoplatystoma corruscans, *P. reticulatum*, and *Zungaro jahu* (Mateus & Penha, 2007). In addition, the analysis of the data obtained by the Sistema de Controle da Pesca (Fishing Control System) in Mato Grosso do Sul indicates that sportfishing is stable since 2007 and the professional fishing indicates stability since 2004 (Catella, Campos, & Albuquerque, 2016). This information indicates also that the fish control measures have been effective, such as a 4-month closure during the reproduction period, the minimum size for the different species, the bag weight limit, and fishing hook as the only fishing tool.

An Agenda for the Pantanal Wetland

The conservation of the Pantanal wetland requires an agenda whose aims are shared by all stakeholders, including scientists, policy makers, politicians, landowners, local communities, educators, governmental organizations, tourists, and private companies. This agenda is necessary to address major existential threats to the Pantanal, such as the land-use changes in upstream areas (e.g., Brazilian Cerrado, Bolivian Chaco), the intensification of cattle ranching, large infrastructure projects, and climate change to name a few. To

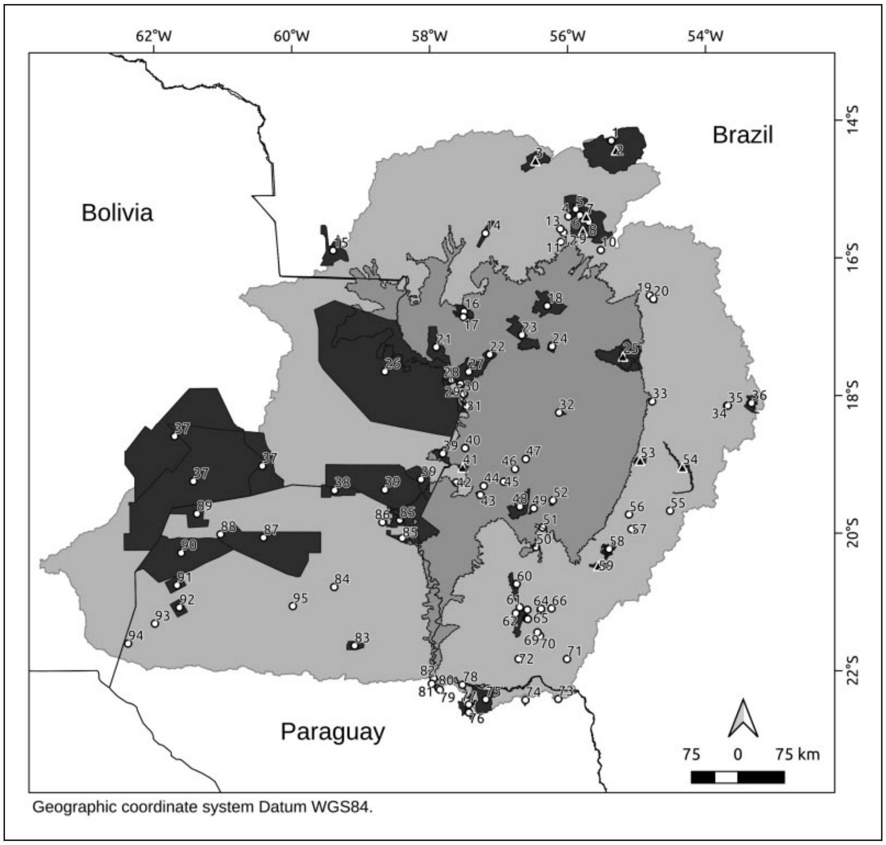

Figure 2. Protected areas (darker gray areas) total or partially located in the Upper Paraguay River Basin (lighter gray area) and the Pantanal wetland (medium gray area), in Bolivia, Brazil, and Paraguay. The numbers refer to the information on each area available in online Appendix 1.

be effective, such an agenda must be comprehensive and represent common ground to different stakeholders. Issues identified in the agenda need to be of broad reach, present a positive impact perspective, and need to be agreed upon as a guide for the use and conservation of the Pantanal. Inspired by Finlayson et al. (2018), we point propose the following agenda:

1. Expansion of the protected area network by including ecologically relevant features, improving landscape connectivity, and ensuring representation of the ecological and biogeographic heterogeneity of the Pantanal;
2. Maintenance of Pantanal Ecosystem Services by halting the conversion of wetlands to other types of land use while maintaining the flood pulse and providing multiple cobenefits to biodiversity and human well-being;
3. Prevention of species loss through the development and adoption of adequate policy instruments that reduce and prevent overfishing, poaching, loss of native vegetation, simplification of the landscape, exploitation and trade of threatened species, and introduction of exotic species;
4. Increase of outdoor education to improve awareness on wetland values and sustainability;
5. Promotion of conservation and wise, multiple-user management approaches by supporting ecologically sound while avoiding ecologically destructive investments in the Pantanal;
6. Promotion of green technologies for infrastructure projects as well as the adoption of renewable energy sources that help to avoid adverse environmental impacts on the Pantanal ecosystems;
7. Protection of water resources against point-source pollution (urban and industrial sewage, fish farming, and swine farming effluents) and diffuse pollution (sediments from soil erosion, fertilizers, agrochemicals, and toxic mining dumps) that may directly or indirectly impact Pantanal ecosystems;
8. Development of compensation programs (tax incentives, rewards for environmental services, etc.) for landowners and local communities that adopt scientifically sound conservation strategies that are based on reliable sustainability indicators and are focused on biodiversity conservation, ecological restoration, ecosystem services, and social responsibility;

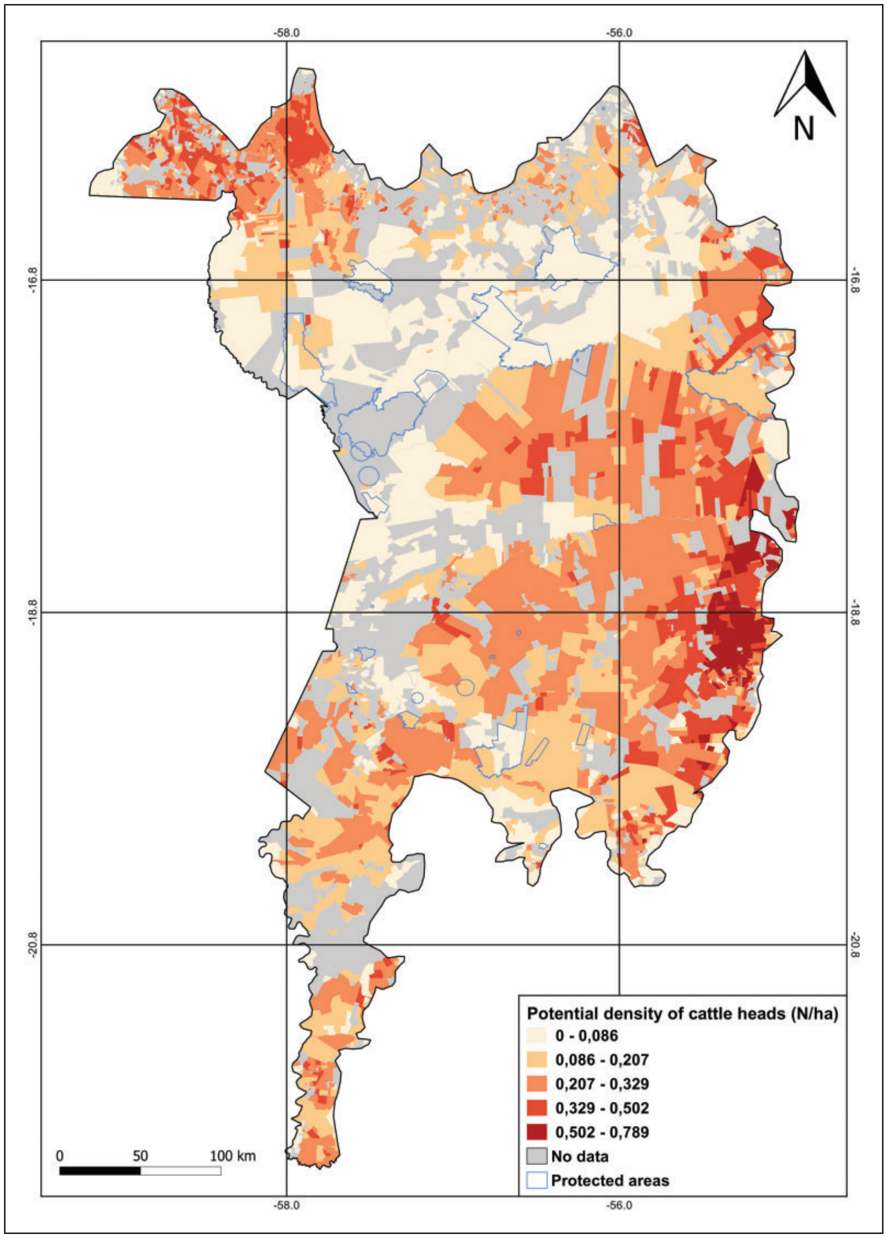

Figure 3. Potential cattle head density per cattle ranch in the Brazilian Pantanal wetland, based on pasture and grassland vegetation maps extracted from MapBiomas v 3.1 (http://storage.googleapis.com/mapbiomas-public/COLECAO/3_1/CONSOLIDACAO/PANTANAL.tif), the total area of pasture per property, the occupation rate of cattle heads per municipality (Oliveira et al., 2016), and the size of the property.

9. Development of a marketing strategy for increasing the value of local labor and products, especially those obtained from environmentally friendly production systems; and
10. Implementation of long-term biomonitoring to assess overall ecosystem health, including chemical contamination and biodiversity, and to support decision-making processes at a regional scale.

This proactive agenda embraces interfaces of particular interest regarding their challenging contexts and opportunities. Here, we suggest and discuss a list of 11 issues and threats, evaluate their significance, and provide examples on how science is already being applied to address the issue.

Land Use and Sustainability in the Pantanal

Inside the floodplain, human interventions in the landscape may result in considerable environmental changes (see Alho, Lacher, & Gonçalves, 1988; Calheiros, Oliveira, & Padovani, 2012; Harris et al., 2005; Junk &

Da Cunha, 2012; Killeen et al., 2007; Miranda, Paranhos Filho, & Pott, 2018; Pinto-Ledezma & Mamani, 2014; Rossetto & Girardi, 2012; Tomas, Mourão, Campos, Salis, & Santos, 2009), raising the need for implementation of effective conservation measures and new restoration approaches in the region. Changes on land use are linked to Points 1, 2, and 3 of our proposed agenda for the Pantanal. Perhaps the most significant land-use change in the Pantanal over the past decades has been the intensification of the traditional extensive cattle ranching to increase economic yields. This intensification has led to the replacement of native vegetation and grasses with exotic, African grass species (Miranda et al., 2018). The result is an increasing simplification of the landscape, with loss, fragmentation, and degradation of natural habitats and severe negative impacts on biodiversity and ecosystem services (e.g., Barbosa da Silva, Arieira, Parolin, Nunes da Cunha, & Junk, 2016; Dorado-Rodrigues, Layme, Silva, Nunes da Cunha, & Strüssmann, 2015; Nunes, 2015; Silveira, Tomas, Fischer, & Bordignon, 2018; Thompson & Velilla, 2017; Tomas, 2017; Tomas, Freitas, & Pereira, 2013).

A fundamental question is how to balance economic activities with biodiversity conservation and maintenance of ecosystem services. Several approaches have been developed by collaborative research networks, research projects, and conservation initiatives. Among these approaches, we may include the Fazenda Pantaneira Sustentável and its component Fazenda Pantaneira Biodiversa, which are diagnostic systems based on indicators developed by Embrapa Pantanal and its collaborators (Santos et al., 2017; Tomas et al., in press). The Fazenda Pantaneira Sustentável system may be a suitable tool in certification schemes, aiming sustainability, value aggregation, and marketing purposes and is linked to Point 9 of our proposed agenda for the Pantanal. Other examples, such as the initiative of Instituto Homem Pantaneiro aiming the recovery and conservation of headwaters of the Upper Paraguay River Basin, the Wetlands International Blue Corridor Programme ("Corredor Azul"), and the PaCha (Pantanal-Chaco) Initiative supported by the Netherlands Ministry of Foreign Affairs, coordinated by World Wide Fund for Nature (WWF-NL) and IUCN-NL, and implemented by seven civil society organizations in Bolivia (4) and Paraguay (3), have potential positive impacts as their approach goes beyond local scale and involve several aspects of conservation.

The Pantanal has been given the status of Biosphere Reserve by UNESCO in 2000, and part of the Paraguayan Pantanal is included in the Gran Chaco Biosphere Reserve in Paraguay. These Biosphere Reserves provide an excellent opportunity for broad-scale efforts to improve the interfaces between conservation, policy, and economy.

Bottom-up approaches may also be suitable in the search of sustainable development and are on the implementation process in the Pantanal. The first is focused on the Model Forest initiative first implemented in Canada in the 1980s (https://imfn.net/) and is presently implemented in more than 40 countries (6 initiatives in Brazil). For the Pantanal, the adoption of this approach has been discussed as a Model Landscape initiative, and the main goal is to unite different stakeholders of a specific region to discuss and adopt steps necessary to improve local sustainability, to establish local governance without dependence on governmental regulation, to improve knowledge and experiences exchange, among other principles. The second is the Working Land and Seascapes program at the Smithsonian Institution, in the United States, in which researchers use science to understand critical ecosystems across the globe—and then share that knowledge, working alongside communities to improve conservation management practices and policies (https://wls.si.edu/). Both have no legal binding, and they are strongly based on the local stakeholders' will to seek better management of the territory and may be adequate, unifying strategies that comprehend most of the key issues of conservation and sustainable development.

Beyond the development of solutions, scientific research is already informing current debates on policies focused on land use and sustainability in the Pantanal, such as the Brazilian Senate proposition of a specific Federal legislation for the Pantanal (Senate Law Project 750/2011). This legislation is required by the Brazilian Constitution from 1988 and should establish the basis for the sustainable use of the Pantanal as National Heritage. Specifically, scientific knowledge has been the basis of several inputs to make sure those decisions and regulations are in agreement with the current understanding of ecosystem functions and services. Also, scientists have contributed to the discussions concerning fisheries and conservation of fish resources in MT (Law no. 9794, Estado de Mato Grosso, 2012) and the creation of a Reserva de Desenvolvimento Sustentável (Sustainable Development Reserve) in the Barra do São Lourenço region near Corumbá, MS (Chiaravalloti, 2017b, Chiaravalloti, Homewood, & Erikson, 2017). Significantly, fisheries regulations have been based on the results from scientific research on fish population dynamics and reproductive biology (e.g., Resende et al., 1995).

A largely overlooked opportunity to advancing sustainable development in the Pantanal is the creation and implementation of programs that provide payments for ecosystem services, such as biodiversity conservation, restoration, and other environmental services.

Paraguay developed a law for payment of environmental services in the Pantanal under the voluntary mechanisms for Reducing Emissions from Deforestation and Forest Degradation (REDD) (http://www.reddprojectsdatabase.org/view/project.php?id=158). In Pantanal, the only known policy Program for Environmental Services Payment recently approved by the MS state in Brazil: (Estado de Mato Grosso do Sul, 2018). However, Schulz, Ioris, Martin-Ortega, and Glenk (2015) state the development of more and larger payments for ecosystem services programs will require increasing awareness among decision makers.

Similarly, there may be opportunities to establish offsetting compensation policies for conservation. This will require the adoption of innovative approaches based on land prices, ecological knowledge, and conservation priorities as parameters to define the offset areas and mechanisms capable of achieving effective outcomes in conservation, with no net loss in biodiversity (Tomas et al., 2018). Such a policy might generate a compensation market in the region, in favor of the landowners in the Pantanal that have conserved the natural landscape in their properties.

Outside Effects

Agricultural Expansion

In the Pantanal floodplain, nearly 80% of the native vegetation remains well conserved, yet more than 65% of the vegetation cover in the Cerrado at the surrounding plateaus have been converted into cultivated pastureland and croplands (Roque et al., 2016). The same pattern is currently under development in the Paraguayan Chaco, and less intensively in the Chiquitano Forest of Bolivia, both in the immediate region at the western fringe of the Pantanal (Caldas, Goodin, Sherwood, Krauer, & Wisely, 2015; Waroux, Garret, Heilmayr, & Lambin, 2016; Yanosky, 2013). These broad-scale agricultural expansions are directly linked to Points 6 and 7 of our proposed agenda for the Pantanal, as they are already disrupting natural avulsion process in the Taquari River, MS as well as other rivers that form the Pantanal wetlands. Taquari is one of the main tributaries of the Paraguay River and has been affected by soil erosion in the surrounding plateaus where agriculture has been intensified since the 1970s. There has been almost four decades of discussions, studies, and projects aiming to solve the problem, without practical results (Assine, 2005; Galdino, Vieira, & Pellegrin, 2006; Padovani, Carvalho, Galdino, & Vieira, 1998; Padovani et al., 2002; Safford, 2010). Dredging, channelization, and other direct interventions in the river channel that have been proposed to alleviate the problems should be thoroughly evaluated to avoid irreversible, additional impacts on Pantanal ecosystems. Sedimentation in river channels is one the most severe impacts resulting from nonsustainable agriculture production outside the Pantanal, as the profits yielded in one region (e.g., the Cerrado ecosystem) cause loss and degradation in another, pointing to the need of broader scale environmental and land-use planning. Restoration of forests and Cerrado vegetation, control of erosion, and best practices in the agriculture are key issues to mitigate and solve the problem, and science may play a key role in finding proper solutions.

Mining

Mining is of critical economic importance for the region and occurs mainly at the fringes of the Pantanal. The iron and manganese mines Corumbá (MS) are among the largest in the region. In addition, large and valuable deposits of iron ore are exploited in the Urucum mountain range in Brazil. Iron ore deposits in El Mutun and Cerro Rojo in Bolivia have largely been untouched but are included in expansion plans for mining. Processing of the ore requires large amounts of water and usually leads to severe pollution of streams and groundwater. Storage of heavily polluted mine tailings often fail, frequently destroying downstream habitats and human settlements, polluting rivers and lands, and sometimes causing large numbers of human fatalities. Large dumps of rejected material, some already classified as high risk of damage in case of collapse and irreversible pollution of streams and wetlands, pose environmental threats similar to the two worst mining disasters that recently hit eastern Brazil (see Garcia, Ribeiro, Roque, Ochoa-Quintero, & Laurance, 2017). In addition, the transportation through the Paraguay River, in the case of increased exploitation, generates a demand for interventions in the river to improve navigation/transportation capabilities (see topic on Large Infrastructure Projects in this article). Gold mining occurs in the northern Pantanal, at the Poconé municipality, MT, in the Bento Gomes River basin, very close to seasonally flooded areas. Risks of contamination due to the use of the mercury from gold mining have been reported over two decades (Nogueira, Nascimento, Silva, & Junk, 1997; Nogueira, Silva, & Junk, 1997; Tümpling, Wilken, & Einax, 1995; Vieira, Alho, & Ferreira, 1995). In tropical wetlands, the rate of biomagnification of the mercury in the trophic web is high (Da Silva & Estanislau, 2015; Oliveira, Hylander, & e Silva, 2004; Vieira et al., 1995). Signs of this process have been already found in the Pantanal (e.g., Callil & Junk, 2009; Ceccatto et al., 2016; Del Lama, Rocha, Jardim, Tsai, & Frederick, 2011; Fonseca, Malm, & Waldemarin, 2005; Hylander et al., 2000; May Junior et al., 2017; Pietro-Souza et al., 2017; Vieira et al., 2011).

Exotic Species

Two of the 100 worst invasive alien species in the world (Lowe, Browne, Boudjelas, & De Poorter, 2000) are already present in the Pantanal wetland: the African giant snail (*Achatina fulica*) and feral pigs (*Sus scrofa*; Alho, Mamede, Bitencourt, & Benites, 2011; Harris et al., 2005). Besides these species, hybrids of the African honey bees (*Apis mellifera scutellata*) and European honey bee (*Apis mellifera mellifera*) have been present in the Pantanal for at least five decades; the Chinese mussel (*Limnoperna fortunei*) invaded the Rivers in the region carried by vessels (Sylvester, Boltovskoy, & Cataldo, 2007); two Amazonian fishes have been introduced in the Upper Paraguay River Basin and reached the Pantanal itself: the tucunaré (*Cichla piquiti* and *C. kelberi*) and the tambaqui (*Colossoma macropomum*; Nascimento, Catella, & Moraes, 2001; Ortega, 2015; Resende, Marques, & Ferreira, 2008); one fish species from eastern Brazil has been documented in the floodplain since 1990s, the *Gymnotus sylvius* (Fernandes et al., 2005; Marques et al., 2018; Sousa et al., 2017); free-ranging, untamed populations of water buffalo (*Bubalus bubalis*) are already established in several areas in the floodplain (Harris et al., 2005; Tomas et al., 2010); and lineages of the wild boar (*S. scrofa*) interbred with domestic pig have been introduced in some regions of the Pantanal and its surroundings and is already actively invading the floodplain. Among plants, the most invasive species found in the Pantanal is the tanner grass (*Urochloa distachya* [L.] T. Q. Nguyen), despite other *Urochloa* species (*U. humidicola* [Rendle] Morrone & Zuloaga and *U. decumbens* (Stapf) R.D.Webster.), which are cultivated in the floodplain, may also be invasive. Other plant species such as *Leucaena leucocephala* (Lam.) de Wit have been also reported (Zenni & Ziller, 2011). The impacts of such species on regional biodiversity are still largely unknown. Surprisingly, evidences suggest that wild pigs, for example, do not compete with the native peccaries, adjusting their foraging activity patterns when in sympatry (Desbiez, Keuroghlian, Piovezan, & Bodmer, 2009; Desbiez, Santos, Keuroghlian, & Bodmer, 2009; Galetti et al., 2015; Oliveira-Santos, Dorazio, Tomas, Mourão, & Fernandez, 2011).

Large Infrastructure Projects

Some large infrastructure projects are currently under discussion or in the implementation phase in the Pantanal watershed (Figure 4), including 113 hydroelectric power plants, the Paraguay River Waterway (Hydrovia), and transoceanic roads and a railway. These plans are directly linked to Points 3, 6, and 7 of our proposed agenda for the Pantanal. The projects are part of the Initiative for the Integration of the Regional Infrastructure of South America (Iniciativa para a Integração da Infraestrutura Regional Sul-Americana, 2011) an intended to link economies across the continent.

Hydroelectric reservoirs may cause several impacts and examples include changes in hydrologic signature of aquatic ecosystems, nutrient cycle disruption, and fragmentation of river network (Girard, 2002; Gottgens et al., 2001; Souza Filho, 2013). An ongoing project coordinated by Embrapa Pantanal in partnership with the Brazilian Water Agency and several Brazilian universities (Agência Nacional de Águas, 2018) aims to understand the potential impacts of the set of hydropower projects in the Upper Paraguay River Basin and support the decision-making processes needed to ensure long-term sustainable water use and management.

The Hydrovia entails navigational improvements along the existing Paraná and Paraguay Rivers, linking five South American countries: Argentina, Bolivia, Brazil, Paraguay, and Uruguay (Zugaib, 2006). Extensive interventions, such as channel straightening, dredging, and rock removal, have been planned in the Paraguay River to create more than 3,400 km of navigable river capable of accommodating large vessels and barge convoys (Zugaib, 2006). Most of these irreversible interventions will happen along the 1,270-km section of the river that crosses the Pantanal (Figure 4). Several questions regarding the potential impacts of the Hydrovia remain open (Assine & Silva, 2009; Bucher & Huszar, 1995; Gottgens et al., 2001; Hamilton, 1999; Lourival et al., 1999; Ponce, 1995; Wantzen et al., 2008), such as how the interventions in the river bed will modify the hydrological signature of floodplain ecosystems, and how the combination of climate change scenarios and hydrological changes will impact the Pantanal macroecosystem in a long term. A thorough analysis of these cascading impacts and their role in modifying the Pantanal ecosystems and people's livelihood is urgently is needed. Such an analysis needs to involve experts on biodiversity, hydrology, sociology, economy, geomorphology, and climate.

Other additional infrastructure projects seem to compete with the Hydrovia and with one another. For instance, the southern portion of the Norte-Sul railroad, which runs from Chapada dos Parecis (MT) to Santos port in São Paulo state, and the Hydrovia Paraguay-Paraná, will compete for soy cargo from central Brazil. Other competing projects are (a) the Transoceanic Highway, a transcontinental road planned to connect Brazil, Paraguay, Argentina, and Chile, (b) the paving of the existing highway that starts at Cáceres (MT, Brazil), capable of offering suitable connection of MT state (in Brazil) to Santa Cruz de La Sierra (in Bolivia), and (c) the railroad planned by Bolivian and Brazilian governments, all of them set to improve the

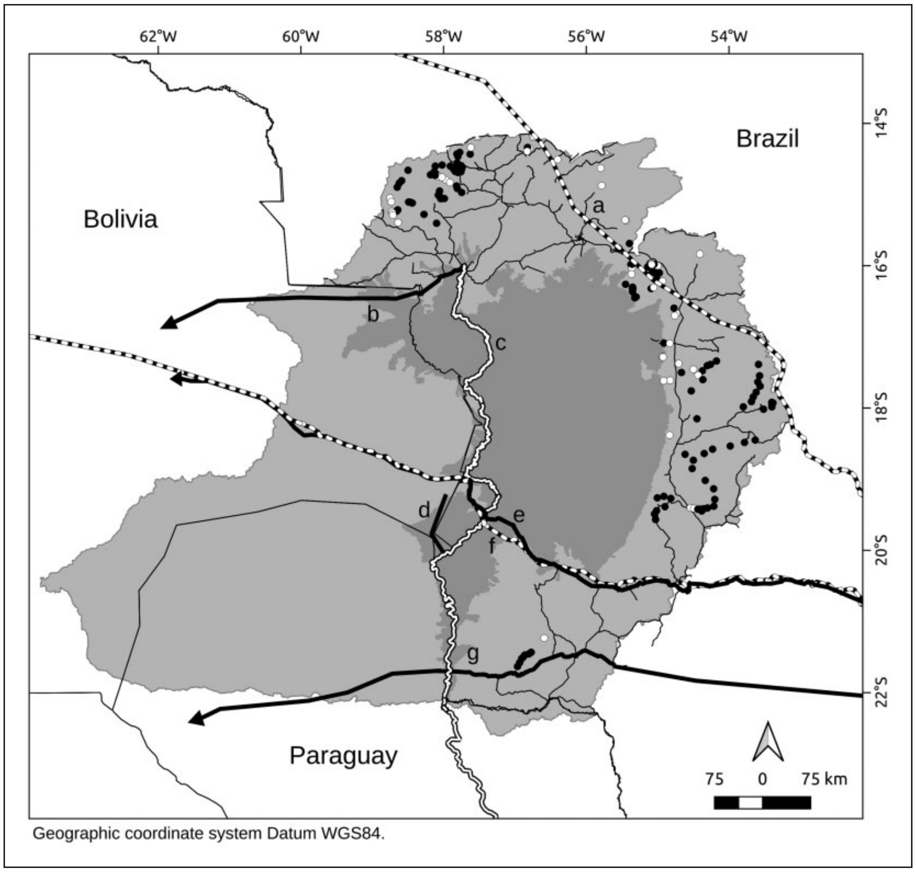

Figure 4. Large transportation and energy infrastructure projects crossing the Pantanal wetlands (dark gray area) or set to the surrounding plateaus of the Upper Paraguay River Basin (light gray area). White dots represent implemented hydroelectric power plants and small hydroelectric centrals; black dots are the planned hydroelectric power plants and small hydroelectric centrals: (a) North-South railway; (b) the BR-070 highway; (c) the planned waterway (Hydrovia) project along the Paraguay River; (d) road linking Puerto Bush to El Mutun mine and Puerto Suarez; (e) the BR-262 highway; (f) the existing railroad planned to cross the Andes in Bolivia; and (g) the Transoceanic highway (BR-267 in Brazil); the fine black lines are the paved roads.

transportation of commodities from Central Brazil to the Pacific Ocean by reaching the Peruvian and Chilean coasts (see Figure 4). It is a compelling idea that these competing transportation projects crossing the Pantanal would be good justifications for an eventual abandonment of the heavy interventions in the Paraguay River to improve the Hydrovia, given the potential impacts in the entire ecosystem. Additional to these projects, there is a planned harbor and accessing roads at Puerto Bush, Bolivia to export iron from El Mutun mine and soybean from Santa Cruz de La Sierra. The location of the harbor is on the banks of the Paraguay River, within the Otuquis National Park area, and fills the Bolivian aspiration for a connection to ocean.

Road kills are an additional consequence of an increased transportation infrastructure. The main paved road inside the wetland is the BR-262, from which nearly 200 km cross the southern Pantanal, where accidents involving wildlife is a daily issue (Ascensão, Desbiez, Medici, & Bager, 2017; Catella, Tomas, & Mourão, 2010; Fischer, Godoi, & Paranhos Filho, 2018a). The Instituto de Conservação de Animais Silvestres has found more than 500 medium to large mammals belonging to 18 species, including vulnerable ones such as the giant anteater (*Myrmecophaga tridactyla*, $n = 124$), killed by vehicles along a stretch of 350 km BR-262 between 2013 and 2014 (Ascensão et al., 2017). Moreover, more than 320 reptiles and 350 birds were killed by vehicles along 210 km of this road during 4 years of monitoring (Fischer et al., 2018a). These studies are examples of the needed information to support mitigation strategies in the existing and on the planned transportation infrastructure in the region.

The Impacts of Global Climate Change

Climate change has a broad implication to the conservation of the Pantanal, but it is linked mainly to Point 10 of our proposed agenda. The UNPCC climate change models suggests a 5°C to 7°C increase in the average air temperature until 2100, whereas changes in rainfall remain remarkably uncertain for the Pantanal (Marengo, Alves, & Torres, 2016; Marengo, Oliveira, & Alves, 2015). Some of the most pessimist scenarios indicate a decrease of 30% in the average rainfall at the Upper Paraguay River Basin until the end of this century (Marengo et al., 2016). So far, there are few studies evaluating the extent of climate change impact on the Pantanal wetland (e.g., Bergier et al., 2018; Girard, Boulanger, & Hutton, 2014; Ioris, Irigaray, & Girard, 2014; Pereira, 2016). Conversely, extreme floods and droughts are expected (Benitez & Domecq, 2014; Marengo et al., 2016). Up to this date, neither federal- nor state-level initiatives are in place aiming mitigation and adaptation to climate change in the region in Brazil. The exceptions are projects related to the citizen science program led by the EcoA to alert people in case of extreme environmental conditions; the GeoHidro-Pantanal flood forecast system conducted by Embrapa Pantanal (https://www.embrapa.br/geohidro-pantanal); the fire risk alert system also developed by Embrapa Pantanal (Sistema de Alerta de Risco de Incêndio para o Pantanal, in a implementing phase); and the Noleedi project that investigates effects of fire on biodiversity in the biggest protected area in Brazilian Pantanal (the Kadiweu Indigenous Land). These initiatives, although not sufficient to fulfill the needs for adaptation and mitigation of environmental impacts, may provide data for the construction of reliable models to support decisions.

Even though the emission of greenhouse effect gases by cattle in the Pantanal is essential to understand the contribution of this activity to the Pantanal ecosystem emission budget (Bergier et al., 2018; Dalmagro et al., 2019; Rojas-Downing, Nejadhashemi, Harrigan, & Woznicki, 2017), achieving this objective is unlikely to reduce the impacts of climate change in the Pantanal. As Brazil's CO_2 greenhouse gases represent less than 4% of the global total (Den Elzen, Olivier, Höhne, & Janssens-Maenhout, 2013) and the emission by cattle 18% of the Brazilian total (Bogaerts et al., 2017), it is clear that zeroing the emissions of the Pantanal herd that represent ~5% of the Brazilian heads (Araujo et al., 2018) will not substantially alter the current global emission scenario. The supposed neutrality of cattle emission in the Pantanal (Bergier et al., 2019) should be cautiously viewed as natural emissions from wetlands should not be used when accounting for anthropogenic emission (Desjardins et al., 2012; Steinfeld et al., 2006). In addition, recent findings by Dalmagro et al. (2019) suggest that the ecosystems may have a much more complex dynamic and contribution to the greenhouse effects, and this should be addressed in deeper studies on the cattle emissions balance.

Focusing on adaptation at this moment is likely to be the most productive strategy for the region. Among the strategies advocated to adapt to climate change is the intensified agricultural systems. However, there are serious questions on the outcomes of the proposed intensification of the cattle production, as the intensified production system concepts are often wrongly applied, for example, to production systems that does not reduce their environmental footprints (e.g., Cambareri & Grant-Young, 2018; Cook, Silici, Adolph, & Walker, 2015; Martin et al., 2018; Pretty & Bharucha, 2014; Wezel, Soboksa, McClelland, Delespesse, & Boissau, 2015). In Pantanal, for instance, cattle intensification production is often viewed as the implementation of large-scale replacement of native vegetation by cultivated pastures, which still presents a relatively low carrying capacity for cattle and causes profound impact on the ecosystems.

Meteorological networks in the tropics still lack detailed data on temperature and precipitation, which may lead to biased climate predictions (Deblauwe et al., 2016; Fernández, Hamilton, & Kueppers, 2013). It is noteworthy the fact that the meteorological station network in the Upper Paraguay River Basin, and especially in the Pantanal, is still very poor and lack long-term, continuous data. This is a clear need requiring a governmental investment given the uncertainties of climate change scenarios for the region. Meteorological stations make available key data for modeling contemporary potential distribution of species and biomes (Elith et al., 2011; Sobral-Souza, Lima-Ribeiro, & Solferini, 2015), as well as to forecast where suitable environments are likely to occur under global warming (Elith et al., 2011). In addition to climate data, long-term biodiversity monitoring is relevant, as time series data make possible to model and predict the effects of climate change on species, populations, and communities. Initiatives such as the long-term monitoring of large vertebrates in the Pantanal, conducted by Embrapa Pantanal, have been able to show strong relationships between flood intensity and population abundance and reproductive performance in some species, such as the Paraguayan caiman (*Caiman yacare*), marsh deer, Pampas deer, and Jabiru stork (Campos, Mourão, Coutinho, Magnusson, & Soriano, 2015; Mourão, Tomas, & Campos, 2010; Pereira, 2016). The Brazilian Biodiversity Research Program sponsored by the Brazilian Ministry of Science, Technology and Innovation is also key to raise information and understandings on biodiversity, based on RAPELD permanent sample plots and standard protocols (Magnusson et al., 2005). Research teams from Mato Grosso do Sul Federal University (UFMS), Embrapa Pantanal, Mato Grosso Federal University (UFMT), and Mato Grosso State University have adopted Brazilian Biodiversity

Research Program protocols, but linkage among these initiatives is still lacking, as well as adequate funding to support continued data collection.

All these information gaps, relationships, uncertainties, and research opportunities are key to evaluate the effects of climate change on the Pantanal wetland, and broad scientific-networks would facilitate integrative studies aiming the proposition of conservation and adaptation strategies, as well as solutions to mitigate impacts. The Pantanal is in a crossroad situation, and decision should be taken now to address conservation issues aiming the mitigation of climate change impacts in the ecosystem.

Biodiversity and Local Communities

Social issues and use of biodiversity are linked in many ways to Points 5 and 9 of our proposed agenda for the Pantanal. Archaeological studies have found that the first human occupation in Pantanal occurred in the Initial Holocene (Bespalez, 2015), but indigenous populations existing at the time of the first European explorations in the 16th century have almost disappeared. Yet some remaining populations of Terena, Guató, the Kadiwéu, the Kinikinau, the Bororo, the Chiquitano, the Chamacoco, the Ishir, and the Mbyá are still present in the Pantanal (Bortolotto & Amorozo, 2012; Bortolotto, Amorozo, Guarim Neto, Oldeland, & Damasceno-Junior, 2015; Domingo & Maria, 2017; Mereles et al., 2000). Many of the indigenous groups merged to "traditional populations," today recognized by the Brazilian Policy on Traditional Peoples and Communities (Brasil, 2007). Local "traditional population" in the Pantanal are composed by mixed indigenous groups and foreigners that still have strong roots with the area and undertake a sustainable livelihood, such as fishing, that are adapted to the ecological dynamics of the ecosystem (Chiaravalloti, 2019, 2017a, 2017b; Chiaravalloti et al., 2017). In spite of legal recognition, most communities in the Pantanal are still invisible to policy makers, or have been oppressed and displaced (Chiaravalloti, 2019). Scientific information indicate the existence of less than 10 local communities (Chiaravalloti et al., 2017; Junk, Nunes da Cunha, Da Silva, & Wantzen, 2011), but EcoA has recorded more than 50 settlements in the Pantanal and in the Upper Paraguay River Basin that may be characterized as traditional populations.

Recent studies are defining some of traditional populations' areas of use or territories (e.g., Chiaravalloti, 2017b, 2019; Chiaravalloti et al., 2017). The combination of the several communities' territories is helping to build what is called "Extractivism Corridor." Led the by the NGO, EcoA, the "Extractivism Corridor" aims to secure tenure rights, promote network between communities, and support the production of nontimber forest products in a sustainable manner. At the moment, discussions regarding the creation of a Sustainable Development Reserve at the confluence of São Lourenço and Paraguay Rivers in the Western Border of the Pantanal are taking place. Wetlands International leads a second interesting initiative in partnership with Mulheres em Ação no Pantanal (MUPAN), the Blue Corredor initiative (Corredor Azul). The main aim is to connect several aspects of community sustainability in the La Plata River basin (which includes the Pantanal), linking indigenous and traditional communities.

Interfaces Among Energy, Water, and Food Security

Technologies that enable the sustainable use of water and energy for food production are still costly, mainly for low-income families inhabiting the Pantanal. Therefore, there is a need for appropriate/humanitarian/social technology (Margolus, Nakashima, & Orr, 2010; Schumacher, 1973), which is based on the merging of traditional knowledge and local materials with the external scientific/technologic information. Pilot projects based on the Water-Energy-Food-Biodiversity Nexus Program from the World Food and Agriculture Organization (Biggs et al., 2015; Stoy et al., 2018) have been conducted in the Pantanal. For example, one project conducted by Embrapa Pantanal and its partners focuses on traditional communities and rural settlements in the region. Another initiative by EcoA, supported by the Nexans Foundation (https://www.nexansfoundation.com/), brought solar panels to the Barra do São Lourenço Community, providing clean energy to allow proper fish storage and household illumination, enhancing local well-being. Another example is the development of a pulping machine suited for "bocaiuva" (fruits of the palm tree *Acrocomia* spp.) to help the Maria Coelho community at Corumbá, MS. The pulp is traditionally used for ice creams, cakes, and other applications. Before this development, women from the community had to pulp fruits by hand, often resulting in a lesion-by-repetitive-effort syndrome.

Worthwhile to be mentioned is the strategic relevance of locally adapted domestic livestock, such as the "Pantaneiro" horse, the "Pantaneiro" or "Tucura" cattle in Brazil, and the "Criollo" cattle in Paraguay. The conservation of these breeds is strategic for food security in the future, as they have developed rusticity and adaptations to a very unstable environment.

Interface Between Biodiversity and the Sustainable Production Chains

The interface between biodiversity and sustainable production chains is linked mainly to Points 3 and 6 of our proposed agenda for the Pantanal. The economy of the Pantanal region consists mainly of cattle ranching, followed by sportfishing and, more recently, ecotourism and mining. Collaborative research is underway aiming to achieve a higher degree of sustainability for these activities. Differentiated production models such as the organic beef led by the Associação Brasileira de Pecuária Orgânica, the Sustainable Pantanal Ranch model led by Embrapa, and the production of origin-linked honey are good examples of collaboration between research, nonprofit institutions and private sectors. However, persisting gaps prevent a fair remuneration for these conservation and sustainability practices in the Pantanal. One gap is the lack of certifications or ecolabeling demonstration of the origin of products based on the traceability that these standards require. The organic beef, despite its high-standard product based on cattle fed exclusively with vegetal items (at least 80% organic), restricted use of allopathic medicine, prohibition of agrochemicals and synthetic fertilizers, is still lacking a more scientifically sound compromise on high-standard biodiversity conservation strategies.

Legislation is a critical aspect in need of a better conformity with conservation goals. The Article 10 of the Brazilian Native Vegetation Protection Act, law number 12.651/2012 (Brasil, 2012) considers the Pantanal as a "restricted use" area, allowing "ecologically sustainable use," but it fails on the definition of the restrict use concept as well as the limits that configure restricted intervention in the ecosystem. On the other hand, the state-level legislation in MS allows the replacement of native vegetation by cultivated, exotic grasses in cattle ranches up to 60% in some cases, depending on the vegetation types in the area to be managed through licensing (Estado de Mato Grosso do Sul, 2015a). This situation displays a conflict between the two pieces of legislation, with the state level being more relaxed than the federal law, as the allowed amount of vegetation replacement being often comparable to other regions outside the Pantanal, not classified as of restricted use. In contrast, the legislation of MT is highly restrictive to interventions in the native vegetation, resulting in a poor development of the cattle ranching. This context indicates a clear need of scientific support to overcome conflicting rules and concepts.

There are however opportunities linked to the economic dimension of sustainability, such as the development of science-based frameworks for improving all stages of beef production; the engagement of different stakeholders along the beef supply chain at regional and global levels; and the improvement of communication, transparency, and credibility of certification and incentive schemes. The needs for search of landscape management/intervention thresholds, environmental certification systems and indicators to aggregate value to products, monitoring programs, and use of biodiversity products to diversify the property income is also likely to require collaborative research between academic institutions and concerned stakeholders (Floto, Yanosky, & Clay, 2013; Yanosky, 2013).

Other emerging activities offer considerable economic potential, but they need strong support from science and policy to gain markets and scale. Among products, we may cite the native rice (*Oryza latifolia* Desv., *O. alta* Swallen, and *O. glumaepatula* Steud.); native nuts (e.g., "cumbaru" *Dipteryx alata* Vogel); other native fruits (e.g., "jatobá" *Hymenaea* spp., "laranjinha-de-pacu" *Pouteria glomerata* (Miq.) Radlk., "bocaiúva" *Acrocomia* spp., "guavira" *Campomanesia* spp., "acuri" *Attalea phalerata* Mart. ex Spreng., "pequi" *Caryocar brasiliense* Camb.); and medicinal plants (e.g., the native "ginseng" *Pfaffia glomerata* (Spreng.) Pedersen), as well as ornamental fish and the native shrimp *Macrobrachium pantanalens*e (Karim, Freitas, Lima, Nascimento, & Hayd, 2015). A recent knowledge network to promote the use and valorization of wild food plants in the Pantanal and Cerrado, led by UFMS, is a good example of how to strengthen the cooperation and exchange of information among scientists and local people and to connect local and global markets (Bortolotto et al., 2016).

Wildlife–Human Coexistence

In the Pantanal, wildlife is exposed to a close contact with human activities, often resulting in historical conflicts such as the predation of cattle by large carnivores (jaguars *Panthera onca* and puma *Puma concolor*; Cavalcanti & Gese, 2010; Zimmermann, Walpole, & Leader-Williams, 2005). When such conflict does occur, large carnivores are often killed (Inskip & Zimmermann, 2009). To overcome this situation, some projects have been developed in the Pantanal, such as those conducted by the nonprofit Panthera (https://www.panthera.org/livingwithjaguars), the Onçafari Association (https://oncafari.org/), the Onças do Rio Negro initiative, and the ICMBio/CENAP, at different locations of the Pantanal. One of the main strategies adopted by these projects is the enhancement and valuation of jaguar populations as a touristic resource (e.g., Tortato & Izzo, 2017; Tortato, Izzo, Hoogesteijn, & Peres, 2017). In addition, the persistence of jaguars and pumas over time at cattle ranches has been included as an indicator in the Biodiverse Pantanal Ranch system (Tomas et al., in press), developed by Embrapa Pantanal and its partners. It represents an attempt to secure the coexistence with these species in certified cattle ranches and the maintenance of species populations at regional scale. For this purpose, and to protect target species under specific public policies, detailed distribution maps are necessary to discriminate properties according its location in relation to the species distribution in the floodplain, which is often not uniform (e.g., Camilo, 2011; Cavalcanti, Azevedo, Tomas, Boulhosa, & Crawshaw, 2012).

Recently, the MT and MS governments passed state-level legislation as an attempt to discipline the tourism based on wildlife observation: the Resolutions CONSEMA 85/11 (Estado de Mato Grosso, 2011) and SEMADE n° 08, 28/04/2015 (Estado de Mato Grosso do Sul, 2015b), as the conflict in this case emerges from the touristic activity itself. The legislation from MS was proposed by Instituto Homem Pantaneiro and Embrapa Pantanal and includes the rules for observation of free-ranging large carnivores in the Pantanal, as well as prohibits the practice of baiting animals to increase sighting probabilities.

The capture of wild animals for illegal pet trade has been monitored by Fundação Neotrópica do Brasil, with focus on turquoise-fronted Amazon parrots (*Amazona aestiva*) in MS (Berkunsky et al., 2017; Seixas & Mourão, 2018). This is the most captured parrot in the world and the most frequently seized species in MS State and in Brazil (Seixas & Mourão, 2000). More than 10,000 turquoise-fronted Amazon chicks have been illegally captured in the past 30 years and sent to the Wildlife Rehabilitation Center/IMASUL at Campo Grande, MS. The number is likely to be only a small part of the total parrot chicks taken from natural nests. It is relevant also to mention the long-term efforts of Instituto Arara Azul in combating the poaching and illegal international trade of hyacinth macaws in the Pantanal, which is a well-known, successful initiative (Guedes, 2002).

Meanwhile, there are still several gaps in the wildlife–human coexistence issue in the region. One of the challenges facing wildlife conservation is the epidemiological interface among domestic animals and native species. Ranches usually have dogs, which may pose several diseases likely to affect wild carnivores, such as canine distemper virus, parvovirus, and parasites. Hence, there is a considerable opportunity for initiatives focused on the responsible ownership of pet animals at the ranches. Wildlife may be considered as "sentinel species" (Rabinowitz et al., 2005) in the interface with domestic animals, especially regarding interchange of disease. For instance, *Leptospira interrogans* has been found in tapirs, Pampas's deer, feral pigs, and white-lipped peccary (*Tayassu pecari*; Freitas et al., 2010; E.P. Medici, personal communication, January 2019). Other diseases shared with domestic animals, such as *Toxoplasma gondii*, bluetongue virus, porcine parvovirus, *Brucelosis*, *Trypanosoma evansi*, and *T. cruzii* have been found in several wildlife species (tapir, peccary, and deer) and feral pigs in the Pantanal and its surroundings (Elisei et al., 2010; Herrera, Abreu, Keuroghlian, Freitas, & Jansen, 2008; Mathias, Girio, & Duarte, 1999; Schabib-Péres, 2010, 2016, Tomich et al., 2009; Zimmermann, 2016), indicating potential health risks for wildlife, livestock, and humans living in the same environment. Owing to the evidences of interchange of disease among wild and domestic animals as well as environmental contamination, there is a great opportunity for collaborative epidemiological studies. The One Health approach (Schwabe, 1984; Zinsstag, Schelling, Wyss, & Mahamat, 2005), which is an interdisciplinary and integrative way of dealing with health issues, may be adequate to manage risks of disease interchange between wild and domestic animals, as well as humans, integrating public health, wildlife diseases, herd sanitary management, and conservation.

Environmental contamination may affect wildlife populations, and it is a relevant, silent issue in the human-wildlife coexistence interface. May Junior et al. (2017) demonstrated that mercury (Hg) contamination is already present in the jaguar population in the northern Pantanal. One of the individuals evaluated had the highest Hg level ($2{,}010.4 \pm 150.5\ \mu g\ g^{-1}$) recorded in wild animals in the world. Mercury also has been found in giant otter from southern Pantanal, but at very low levels (Fonseca et al., 2005). Fish and caiman (*Caiman yacare*) in the Pantanal are also contaminated (Ceccato et al., 2016; Hylander et al., 2000; Vieira et al., 2011).

Finally, it has been remarkably evident the relatively low impact of traditional cattle ranching on wildlife in the Pantanal. There is no notice of any species that became endangered solely due to cattle ranching in the region, even considering the historical conflict between cattle ranching and the large predator populations (Tomas et al., 2010). In contrast, the giant otter (*Pteronura brasiliensis*) was almost extinct in the region due to commercial hunting until the 1967 (Tomas et al., 2010). The traditional extensive cattle ranching usually maintain most of the landscape diversity and complexity, as well as it increases habitat heterogeneity, favoring the biodiversity conservation. However, some research have shown long-term cattle-related alterations of forest vegetation (burning, trampling, logging, and foraging), resulting in hidden degradation and poorer habitat quality for wildlife (Eaton, Keuroghlian, Santos, Desbiez, & Sada, 2017; Tomas et al., 2013). It is remarkable that most of the few endemic and rare plants of the Pantanal (see Pott & Pott, 2009; Wood, Urbanetz, & Scotland, 2016) do occur in vegetation types that are often affected by unsustainable management practice, such as the replacement of the native vegetation by cultivated pastureland. The absence of adequate management strategies for some rare and endemic species have compromised the genetic diversity of their populations (Alves et al., 2018b). The challenge is to overcome the pressure for distorted "intensification" concept of land use in the Pantanal, often assumed solely as an increased extension of cultivated pastures, with consequential simplification of the landscape and decrease habitat quality and availability for wildlife. In this aspect, the Sustainable Pantanal Ranch and the Biodiverse Pantanal Ranch systems may serve as adequate tools as the set of indicators impose limits and reference indexes for landscape diversity conservation and the maintenance of habitat quality (Santos et al., 2017; Tomas et al., in press). Adaptative management and rotational grazing may also be good practices to decrease impacts (Eaton, Santos, Santos, Lima, & Keuroghlian, 2011). Hence, together with the adoption of available antipredation strategies, schedules of payment for ecosystem services, and environmental compensation via proper *offsetting* policies, these sustainable management strategies may compose a comprehensive and effective system to guarantee the conservation of wildlife at cattle ranches and at regional scale. Certification schemes, with conservation being mostly paid by the market, may be a relevant strategy as the consumer's awareness and aspirations may represent one of the strongest forces driving changes in attitudes nowadays.

Tourism as a Sustainability Inductor

The Pantanal is well known by the abundance of its wildlife, which is a result of the high primary productivity and conservation status of the ecosystems in the floodplain. Populations of several endangered species are still abundant, mainly due to the almost pacific coexistence between wildlife and cattle ranching (Tomas et al., 2010). The easy observation of rare, iconic, and endangered species, such as the giant otter, the jaguar, the hyacinth macaw, the marsh deer, the jabiru stork (*Jabiru mycteria*), among others, make the region attractive for tourists. The recreational fishing is a traditional activity due to the high productivity of the Pantanal Rivers. The landscape is equally attractive, composed by a mosaic of forests, savannas, grasslands, and several types of aquatic habitats. The 577 endorheic, brackish water ponds ("salinas") distributed amid 17,000 freshwater ponds (Oliveira et al., 2016) in a matrix composed by forest patches, savannas, and natural grasslands create a unique landscape at the Nhecolândia region of the southern Pantanal.

In addition, the Pantanal is located in a privileged crossroad in the center of South American continent, with touristic routes crossing the region and linking the Andes with eastern Brazil. Pantanal is also close to two relevant touristic areas located in the Upper Paraguay River Basin: Bonito, Jardim, and Bodoquena in MS, and Chapada dos Guimarães and Nobres in MT. The crystal clear waters created by the karstic outcrops of Bodoquena-Bonito-Jardim area and Nobres allow successful snorkeling and diving-based tourism, besides cave visiting. However, there is a variety of environmental threats caused by the tourism itself that include resource consumption, waste generation, infrastructure, and, by its very nature, increased people access to natural areas (Bessa, Silva, & Sabino, 2017), as well as those threats caused by agricultural expansion.

Inside Pantanal, there are also attractive sites such as the Pantanal National Park, the contrasting Amolar mountain range, the Encontro das Águas State Park, the private reserve and its resort owned by Serviço Social do Comércio – Pantanal Bureau (SESC-Pantanal), the historical Coimbra fortress, and the paleontological site where the fossils of the oldest multicellular animal on Earth were found (*Corumbella werneri*), as well as other Ediacaran fauna such as *Cloudina lucianoi* (Adorno et al., 2018), and dolostones with stromatolites (Walde et al., 2015). Archeological sites scattered in the Pantanal have high potential impact for tourism once they are rich in rock inscriptions (petroglyphs; Bespalez, 2015; Girelli, 1994). Nonetheless, most of them are still little valued as touristic products or packages. Costs, lack of infrastructure, access difficulties, lack of formatted routes and products, absence of management plans, as well as preference of the tourism trade to invest only in sportfishing, are some of the barriers that must be overcome to make the tourism a more relevant industry in the Pantanal. Presently, there is a pressure to reduce or even eliminate the amount of fish allowed for sportfishing, despite nothing indicates overfishing (Catella et al., 2016). However, the MS government just passed a Decree n° 15166 (Estado de Mato Grosso do Sul, 2019), regulating the fisheries in the state and reducing gradually the bag size for sportfishing, until it is eliminated. Politically, this type of top-down restrictions may have an appeal in the society and especially to the interests of the sportfishing sector. In this context, soon the tourism industry will need to rely on a catch–release system. In contrast, policies do not address enhancement in the protection of Rivers and wetlands against degradation, damming, agrochemical pollution, sewage, sedimentation, erosion, and deforestation, which affect habitat quality and productivity, the most relevant factors influencing fish stocks.

Some current initiatives deserve to be highlighted because of their potential to be amplified and to strengthen the tourism in the Pantanal. Among them, we may cite the Panthera initiative on jaguar-focused tourism at Porto Jofre region, MT (Tortato et al., 2017), the Onçafari initiative on habituating wild jaguars for observation by tourists at Estância Caiman, MS, as well as the well-developed organization of tourism in Bonito, Jardim, and Bodoquena region, MS. A relevant aspect of the tourism is capacity building. The Environmental

Education and Citizen Science based on birdwatching training led by Instituto Mamede, as well as the WWF-Brasil program on capacity-building addressed to owners of private protected areas to promote tourism, and to develop a supply chain for local consumption by the tourism trade, are good examples of ongoing experiences in the Pantanal region.

These are examples of actions that require science background to safely increase the quality and the relevance of the tourism in the region, which must be amplified to include other species, locals, and types of tourism. In addition, as many lodges and hostels are associated with traditional cattle ranches (Tortato & Izzo, 2017), it creates a protection network capable of maintaining the habitat diversity and its associated wildlife (Junk, 2017), especially when associated with sustainable production chains and remuneration for conservation strategies discussed before. Finally, stakeholder engagement with a biocultural design that facilitates the integration of more-than-biodiversity is required to promote sustainability of the entire social-ecological system in which tourism is inserted (Arts et al., 2018). In our understanding, the tourism is linked to Point 8 of our proposed agenda for the Pantanal.

Education and Communication for Sustainability

Education and communication have a wide influence in the conservation context, and as such, they may be considered as linked to all points of our proposed agenda for the Pantanal, despite Point 4 is obviously related to the education aspect. However, local communities in the Pantanal experience challenges for improving education in general. First, these communities are usually scattered over large areas, often poorly connected by public transportation and, sometimes, completely isolated, when the lower areas flood during the wet season. In addition to transportation difficulties and costs, the limited number of public schools with adequate infrastructure and well-prepared education professionals hampers access to basic education inside the floodplain. Also, the dynamic physical changes of the environment pose additional demands on education professionals in Pantanal schools which discourage government personnel from persevering there, creating a high turnover rate of professionals and discontinuity of the programs.

Several socioeducational initiatives emerged in response to the needs of Pantanal's population, as private, NGO, and governmental collective efforts. The *Jatobazinho School* (sponsored by the ACAIA Institute and the Corumbá Municipality, MS) and the *Escolas das Águas* (conducted by EcoA in partnership with the Corumbá Municipality, MS, the Instituto de Apoio e Proteção a Pesquisa, Educação e Cultura-IAPPEC, and the Brazil Foundation) are good examples of public, private, and third sector collaboration in the Pantanal. The challenge is to define strategies to amplify these experiences and reach large coverage of the communities living in the Pantanal.

As we are nowadays dealing with a Nature Deficit Disturb (Louv, 2008), it is also necessary to approach the causes and motivations of the problem, to achieve a gradual rupture with these causes (Dickinson, 2013). Programs such Citizen Science would be excellent strategies to better integrate local communities to their environment (Forrester et al., 2017; Gouraguine et al., 2019). The proper environmental education represents the desired link between science and community, and it is a relevant tool to support the goals of the Conservation Biology and Sustainability (Benites & Mamede, 2008). Schulz et al. (2019) already call for a integrative perspective on environmental education engaging between researchers, policy makers, and citizens to foster environmental awareness, scientific literacy, and public participation. In the Pantanal, participatory processes would promote environmental education (Sato, Silva, & Jaber, 2014), taking into account the existing experiences and the close relationship between people and environment.

Currently, three environmental formal education initiatives are already in place, such as the Environmental Education Network in MT, Environmental Education Network in MS, and the Aguapé Pantanal Network, which integrate the Brazilian Environmental Education Network. However, those initiatives have been limited in their capability of reaching the communities in the Pantanal. One good example of effective capacity-building program is the Gender, Water & Environmental Education, carried out by MUPAN during 2013 and 2014, created by demand of local communities of Pantanal. The program was prized with "Good practices in training for Gender Equality" of United Nations Women in 2016.

In an even broader view of education for the conservation in the Pantanal, efforts should be made on improving communication for sustainability, with the goal of reaching a larger portion of the society through creative and accessible language to deliver critical scientific information. Most of the available communication material about the Pantanal focuses solely on attracting tourists. Effective information, education, and communication materials are an important components of any comprehensive education campaign and should include not only aspects related to economic activities (e.g., fishing) but mainly deliver accurate information on the ecosystem, its biodiversity, threats, values, and conservation challenges. Some ongoing species conservation projects in the Pantanal, such as Arara Azul Project, Peixes de Bonito Project, Lowland Tapir Conservation Initiative, and Panthera initiative, are good examples of effective communication programs, as they are constantly releasing informs using several media and the press, thus becoming well known by the general public. One example is the booklet published by Panthera containing a compilation of scientific information about the jaguar, directed to the Pantanal workers, farmers, schools, and communities (Tortato, Bonanomi, & Hoogesteijn, 2015). The Center of Environmental Interpretation conducted by SESC-Pantanal is another good example of a more comprehensive education. In addition, the Pantanal region has a science communication magazine (Ciência Pantanal), initially supported by the Wildlife Conservation Society, and currently sponsored by the WWF-Brasil, which is the main media vehicle for scientists to present and discuss the Pantanal with the whole society, with language and editorial profile adequate to this purpose. One interesting experience in Paraguay is the community-run radio station at Bahía Negra, supported by Guyra Paraguay and World Bank, providing information on wildlife and nature.

Ongoing programs, such as the BIOTA-MS, which is a partnership between the Brazilian Studies and Project Financing Agency and the MS government, would be ideal a platform to include an effective communication initiative to meet the objectives of the project, as other similar successful initiatives in Brazil. Under a unified perspective, it would be interesting the establishment of a BIOTA-Pantanal program, involving the MT and MS states, similar to the most effective model in Brazil, the

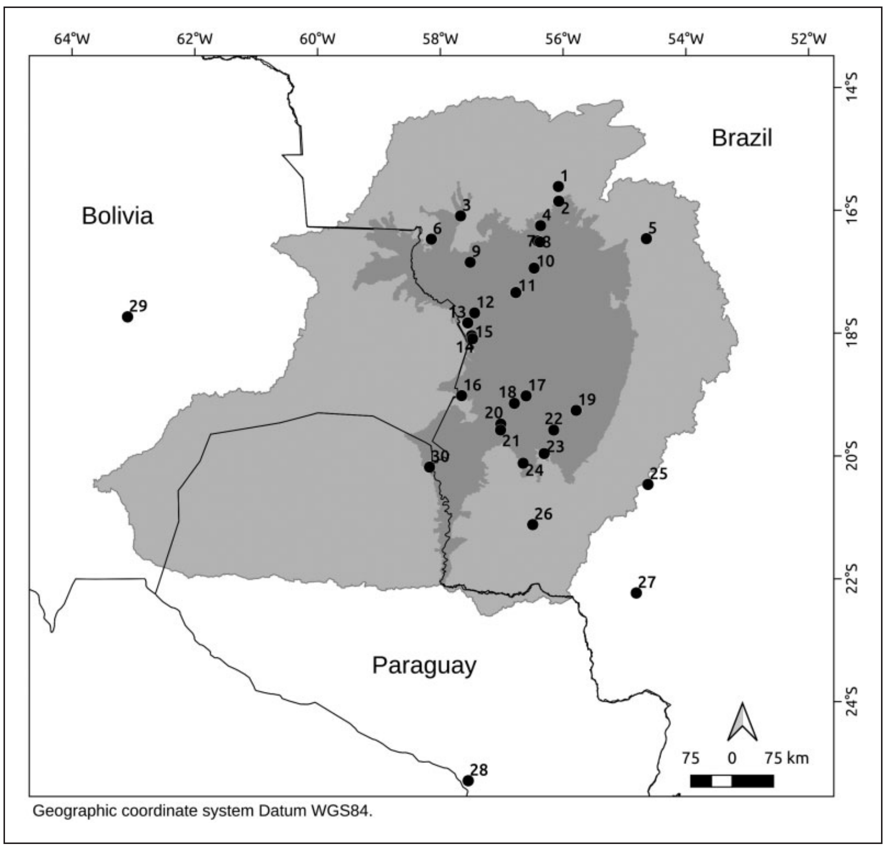

Figure 5. Infrastructure to support research in the Pantanal wetland (dark gray area) and its surroundings. Field stations—7: UFMT Field Base, Poconé, MT; 9: Taiamã Ecological Station facilities; 11: Panthera field station, Poconé, MT; 10: Pantanal National Park facilities, Poconé, MT; 14: ECOA Field Base at Amolar mountains, Corumbá, MS; 15: IHP field station, Corumbá, MS; 17: Embrapa's Nhumirim field station, Corumbá, MS; 21: UFMS Field Base, Miranda, MS; MT; 30: Estación BiológicaTres Gigantes. Universities: 1: UFMT campus and CPP headquarters at Cuiabá, MT; 3: UNEMAT Campus at Cáceres, MT; 5: UFR campus at Rondonópolis, MT; 16: UFMS Campus Pantanal, Corumbá, MS; 25: UFMS, Uniderp, UEMS, and UCDB campuses at Campo Grande, MS; 26: UFMS campus at Bonito, MS; 27: UFGD campus at Dourados, MS; 28: Universidade Nacional de Asunción and Museo Nacional de Historia Natural del Paraguay at Asunción; 29: Universidad Gabriel René Moreno and Museo Noel Kempff Mercado, at Santa Cruz de La sierra. Research institutions: 16: Embrapa Pantanal headquarters at Corumbá, MS; 25: Embrapa Beef Cattle research center at Campo Grande, MS. Private land open to field research: 4: Pirizal, Poconé, MT; 5: Fazenda Experimental, Cáceres, MT; 6: Baía de Pedra ranch, Cáceres, MT; 8: SESC-Pantanal, Poconé, MT; 10: São Francisco do Perigara ranch, Barão de Melgaço, MT; 13: Acurizal ranch, Corumbá, MS; 16: UCDB field base at APA Baía Negra, Corumbá, MS; 18: Alegria ranch, Corumbá, MS; 19: Baía das Pedras ranch, Aquidauana, MS; 20: São Bento ranch, Corumbá, MS; 22: Barranco Alto ranch, Aquidauana, MS; 23: Caiman Ecological Refuge, Miranda, MS; 24: San Francisco ranch, Miranda, MS.

BIOTA-Fapesp Program from São Paulo state. Perhaps, this type of program may eventually involve Bolivian and Paraguayan institutions, with consistent scientific communication to help the buildup public awareness on biodiversity and conservation.

Collaborative Use of Research Infrastructure

The scientist network engaged in this article has published more than 1,000 articles on the Pantanal in different knowledge areas, such as environmental impacts, biodiversity, economy, social science, hydrology and limnology, climate, cattle ranching, sustainability indicators, fisheries, tourism, and education. They compose an initial group of 116 researchers from more than 40 institutions located in the Pantanal region as well as other institutions in Brazil and abroad, including members from at least 9 countries (Brazil, United States, Germany, France, Australia, Bolivia, Paraguay, Colombia, and United Kingdom). There is still room to increase collaborative research on the Pantanal issues, taking advantage of the existing partnerships and infrastructure in the region.

"Research infrastructure" involves facilities, resources, and related services that are used by the scientific community to conduct science, technology, and innovation projects. Taking into account just the facilities already existent in the Pantanal (Figure 5), we can highlight many opportunities to improve the connection between people and organizations.

At least five Zoological and six Botanical collections are consolidated in the region (see Alves et al., 2018a; Moraes, 2006; Sabaj, 2016; Tomas et al., 2017), aiming basic research on biodiversity. However, these collections deserve support for enhancement, informatization, interchange, and continued capacitation of their personnel to improve their relevance, in accordance to the directions elaborated by Peixoto et al. (2006). Several institutions own field stations in the Pantanal (Figure 5), composing a considerable network of infrastructures to support field research and monitoring programs at large scale in the region. In addition, but not less important, there are many ranches that continuously provide support for field research (see Figure 5).

Networks such as the BIOTA-MS Program for Biodiversity in MS, the Long-Term Ecological Research Program, the Rios-Vivos Network, as well as the Zona de Integración del Centro Oeste de América del Sur, and the Model Forest network are examples of collaborative initiatives capable of connecting different expertise in search for solutions addressing conservation, economic, and social issues in the region. The CASEST network (French acronym for "Anthropogenic Constraints to Tropical Social-Ecological Systems") is a long-term program involving UFMS, the University of Angers (France), and the Sustainable Research Unit at the Nelson Mandela University (South Africa) to investigate the interfaces between nature and society, particularly between wildlife and agricultural practices around protected areas. The integration of most of these initiatives is an open avenue that needs the development of common agendas, decreased bureaucracy, long-term funding, and improvement of the interfaces with the policy and decision-making agendas.

Concluding Remarks

In summary, facing these timely demands and perspectives, it is necessary to favor the strengthening and a closer approximation of the interface between science and policy-making processes, aiming the sustainable use of the Upper Paraguay River Basin and the Pantanal wetland. The difficulties for such initiatives are historical in Brazil, Bolivia, and Paraguay. The scientific community has been largely ignored by decision makers when drafting laws and other types of public policies (Azevedo-Santos et al., 2017). If the current gap between science and conservation policies is not filled out, the countries will threaten the maintenance of their natural capital and, consequently, the sustainability of essential social activities in the long term (Azevedo-Santos et al., 2017). Unfortunately, the Brazilian science on environment sustainability and biodiversity conservation is under a strong cutback by the Brazilian government (Dobrovolski et al., 2018; Fernandes et al., 2017; Magnusson et al., 2018), and this stringent funding policy is likely to affect research in the Pantanal as well.

The challenges in conserving the Pantanal wetland would require a suitable level of organization by scientific community, as well as the construction of an efficient and bold relationship with the governments and legislators, landowners, and local communities. For this, a common agenda must seek the establishment of a bridge over the gap among these sectors of the society, in a collaborative approach. Trust and credibility are two of the main aspects that should be the basis of this approach to overcome the dilemma between economic growth and environmental conservation in the Pantanal, as pointed by Ioris (2013). An enhanced stakeholder involvement in the definition of a research agenda in the Pantanal has been defended by Schulz et al. (2019) to strengthen the practical relevance of research in addressing environmental management challenges in the Pantanal.

To inform and act toward integrated political action and sustainability policies, scientists have to overcome the historical barriers that have restricted them to their nations and research fields and produce good sustainability science. The steps suggested by Miller (2013) and Miller et al. (2014) are a possible guidance, and scientists should maintain a clear view of how and why the science may contribute to the move toward what is collectively defined as sustainability and at same time avoid the risks inherent to transformations for sustainability pointed out by Blythe et al., (2018). Scientists should also be aware of the societal transformations proposed by such an agenda and needed shifting in the burden of response to sustainability threats from those who have caused them to those who are the most affected by them. In addition, it would be necessary to evaluate the possible outcomes of this agenda intermediated by the views and experiences of different social groups. Failure to recognize that political processes underpin the changes proposed by this agenda will undermine the capacity of scientists help in the mobilization of the society for the conservation of the Pantanal.

We truly believe that a functional science network, as well as stakeholder involvement, can booster the collaborative capability of the participants to generate creative ideas and solutions for addressing the big challenges faced by the Pantanal wetland.

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Supplemental Material

Supplemental material for this article is available online.

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