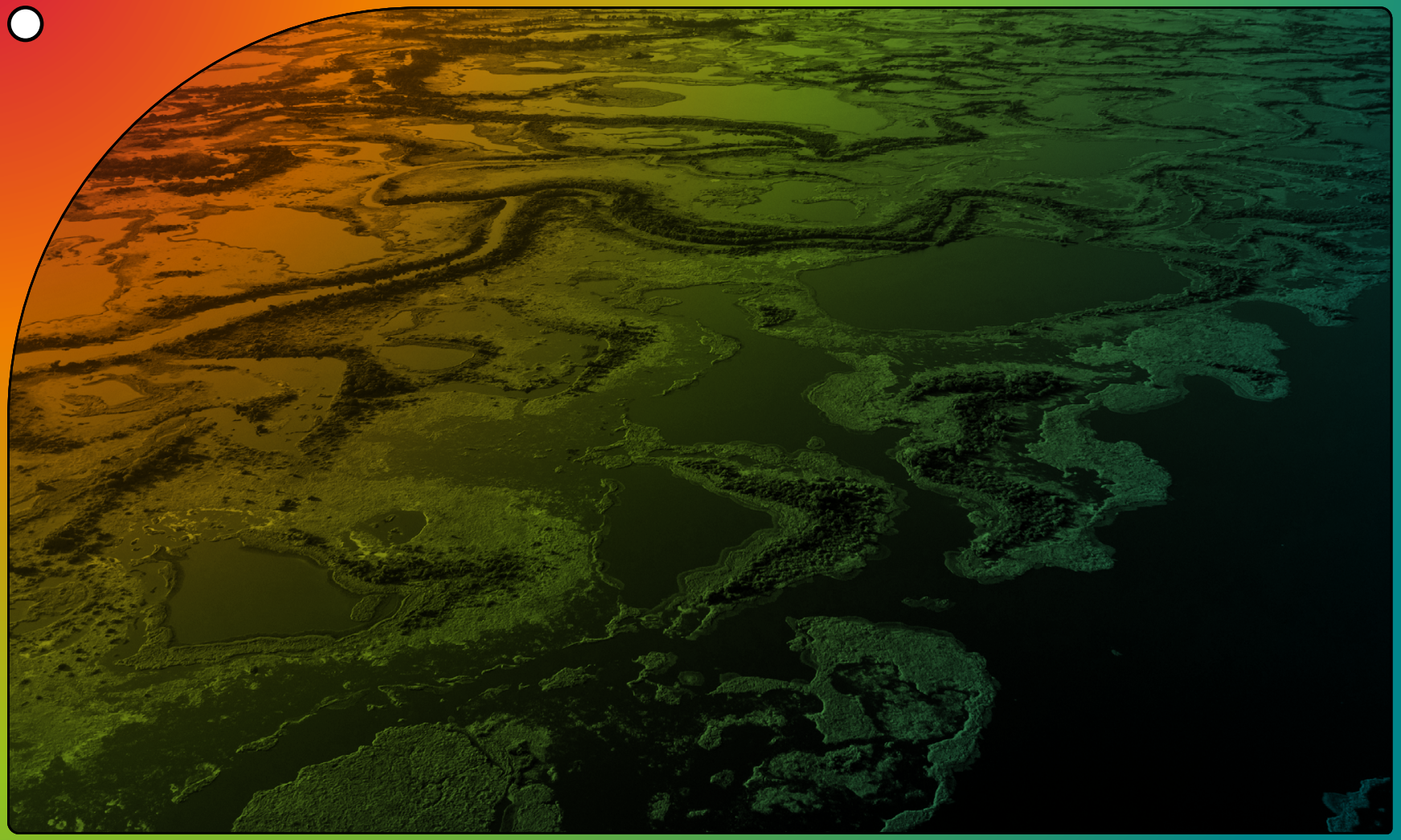
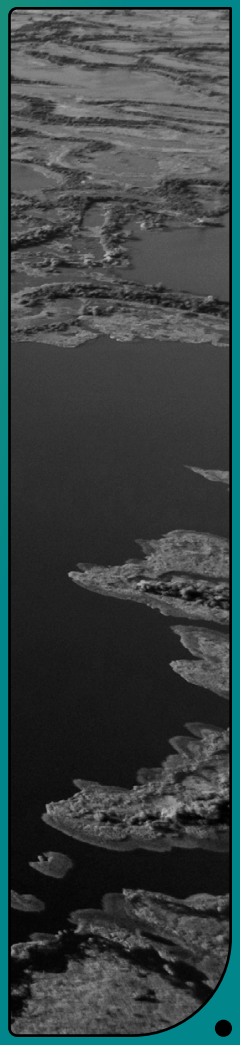




TECHNICAL NOTE

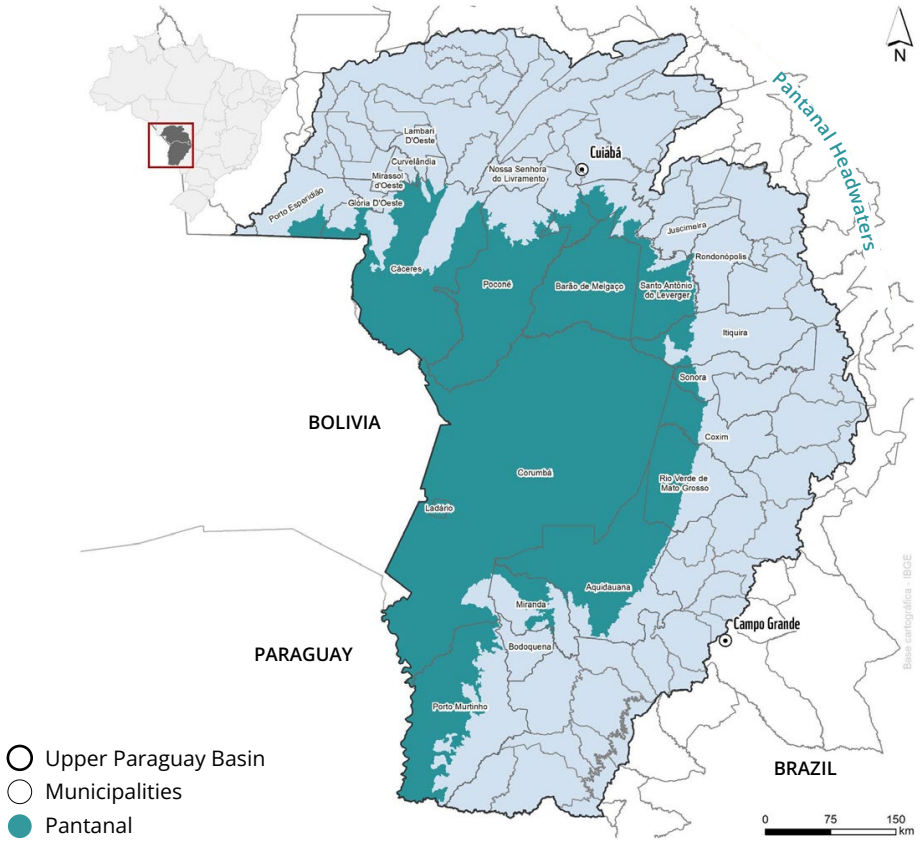
EARLY WARNING TO MITIGATE IMPACTS OF DROUGHT IN THE PANTANAL

WWF

An unprecedented monthly mapping study of the water surface in the Pantanal plain, carried out by ArcPlan, supported by WWF-Brazil and financed by WWF-Japan, was based on the high resolution of the Planet satellite sensors and reveals a worrying reality: the Pantanal is getting drier and drier, which signals increased threats to its biodiversity, natural resources and the way of life of the Pantanal population.

FIGURE 1

Location map of the Upper Paraguay river basin and Pantanal



THE PANTANAL IS GETTING DRIER AND DRIER

1 THE WATERS OF THE PANTANAL

The Pantanal is the largest continental wetland on the planet and was recognized as a National Heritage Site by the Brazilian Constitution of 1988. In addition, in 2000 it was recognized by Unesco as a World Natural Heritage Site and Biosphere Reserve. Throughout the formation of this ecosystem marked by periodic flooding of the plain (flood pulses), there has been a selection of plant and animal communities, soil micro-organisms, with a high physiological tolerance and life cycles (e.g., reproductive and migratory) adapted to periods of flooding and drought. Subsequently, flood pulses have also influenced the adaptation of the way of life of traditional peoples and communities, who link their economic and subsistence activities to the water calendar.

THE PANTANAL IS THE LARGEST CONTINENTAL WETLAND ON THE PLANET

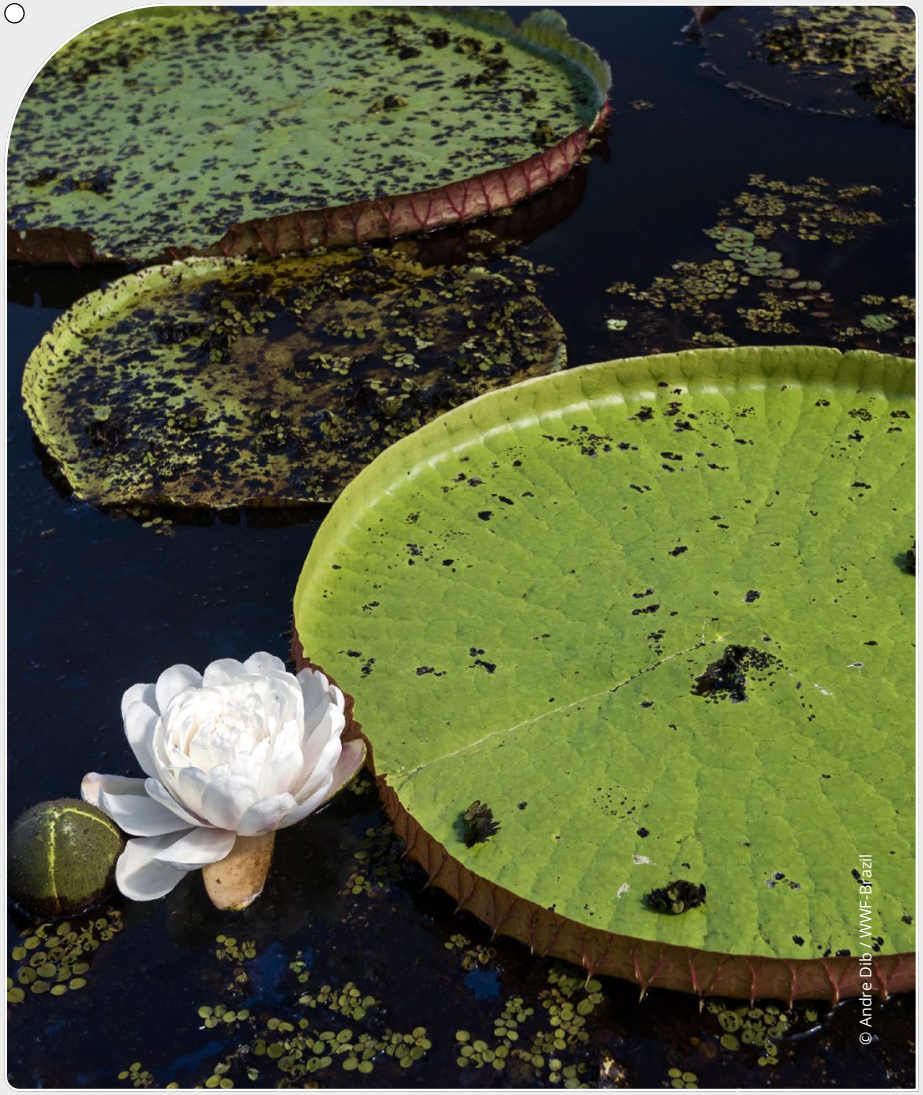
The dynamics of flood pulses are a structuring element of more than 150,000 km2 that comprise the biome. The BAP's rainy season runs from October to April and the dry season from May to September. While this dynamic makes the landscape adapted and resilient, it also makes it vulnerable. The extent of the flooded area depends on the amount of water provided by the plateau and the water level of the Paraguay River, which needs to be full in order to overflow and dam the waters that reach the plain. Alterations to this system, which depend on climatic conditions within the Upper Paraguay river basin, jeopardize the connection between rivers and flood plains, a phenomenon essential for maintaining aquatic biodiversity. In the process of variation between droughts and floods, flooded areas have their vegetation flooded, at which time part of it dies and decomposes, forming the organic detritus that serves as food for detritivores fish, especially abundant in floodplains such as the Pantanal[1].

The reduction in wetlands not only raises concerns about the conservation of the Pantanal but also about the change in use and occupation of the upper areas of the basin, the headwaters region, where the main tributaries of the Paraguay River are located. It is not by chance that these areas are concentrated in farming and cattle-raising activities, and they are impacted by changes in the climate, especially in the rainfall regime.

1 Resende, E. K. Pulso de inundação: processo ecológico essencial à vida no Pantanal. Corumbá: Embrapa Pantanal, 2008 (ISSN 1971 - 7223; 94)

THE REDUCTION IN WETLANDS NOT ONLY RAISES CONCERNS ABOUT THE CONSERVATION OF THE PANTANAL BUT ALSO ABOUT THE CHANGE IN USE AND OCCUPATION OF THE UPPER AREAS OF THE BASIN

In addition, the conversion of natural areas to pasture and agriculture, especially in the headwaters (the plateau area of the BAP), intensifies the processes of soil erosion and sediment transport, which gradually alter the physical and chemical characteristics of the lowland water bodies[2]. The soil's ability to store and transport water is a crucial factor in regulating the water balance and controlling the transport of sediments and pollutants, both to surface and groundwater bodies (aquifers)[3], since the availability of water in the soil is not only a function of precipitation but also of the soil's structure, depth and organic matter content[4]. For this reason, practices such as the ecological restoration of wetlands, known as Permanent Preservation Areas (PPAs)[5], are an example of an urgent measure to guarantee the minimum integrity of river characteristics and water quality in the BAP.



2 Oliveira, M. D., Calheiros, D. F. & Hamilton, S. K. Mass balances of major solutes, nutrients and particulate matter as water moves through the floodplains of the Pantanal (Paraguay River, Brazil). (2019). Revista Brazileira de Recursos Hídricos, v24. doi.org/10.1590/2318-0331.231820170169

3 Doran, J. W., Coleman, D. C., Bezdicek, D. F., Stewart, B. A., Doran, J. W., & Parkin, T. B. Defining and Assessing Soil Quality. Defining Soil Quality for a Sustainable Environment. (1994). doi. org/10.2136/sssaspecpub35.c1

4 Prentice, I. C., Cramer, W., Harrison, S. P., Leemans, R., Monserud, R. A., & Solomon, A. M. A Global Biome Model Based on Plant Physiology and Dominance, Soil Properties and Climate. (1992). Journal of Biogeography, 19(2), 117. doi:10.2307/2845499

5 The Pantanal Law (Lei do Pantanal), State Law 6160 of December 18, 2023, extended the definition of PPA to other vegetation formations, such as salt marshes and abandoned meanders.

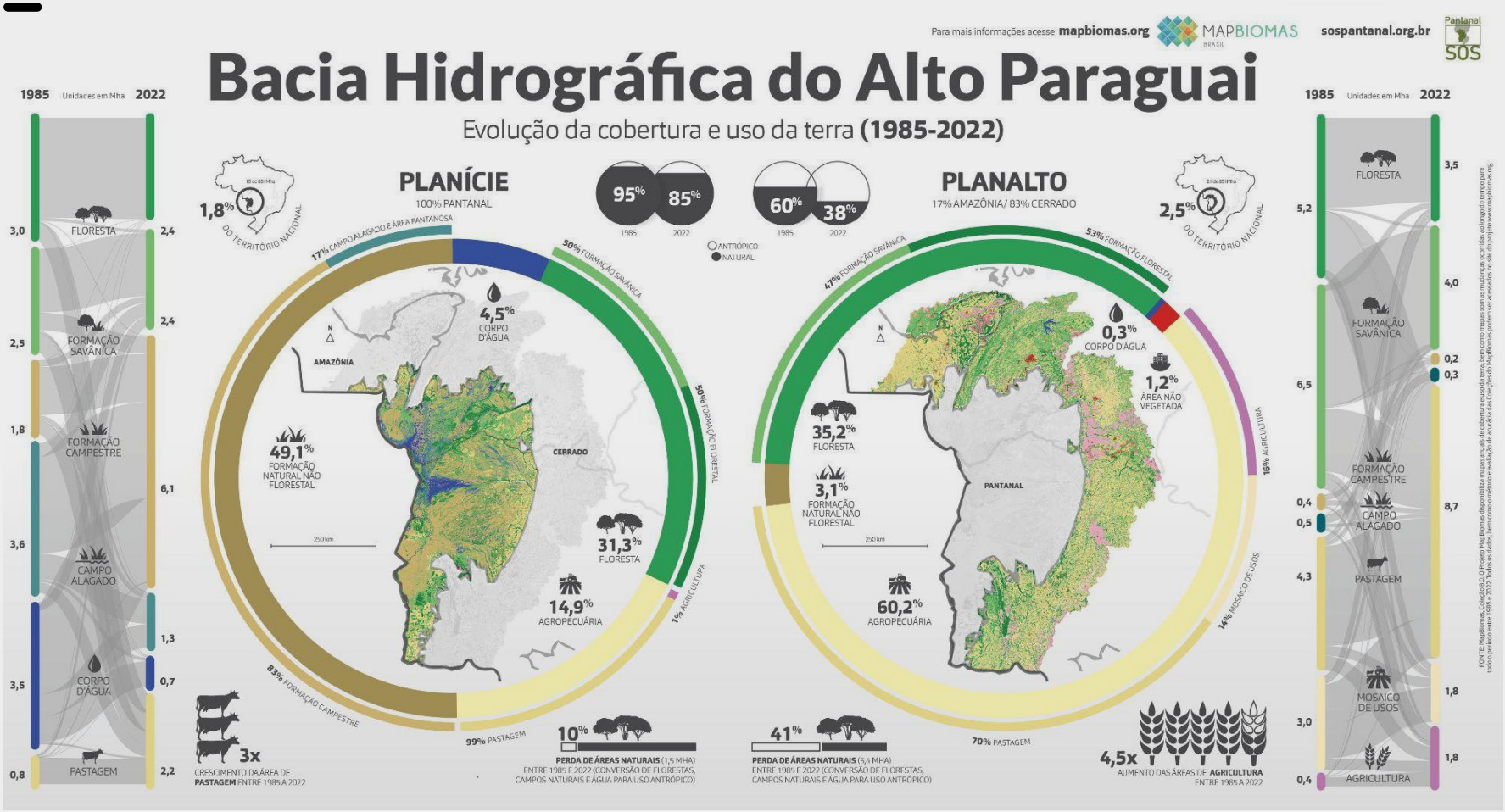
Cumulative processes of degradation of the biome - interruption and regulation of water flows between plateau and plain, due to the construction of dams or roads and drains, associated with deforestation and fires - accentuated by climate change are bringing the Pantanal closer to a tipping point[6]. Researchers have been warning for a long time about changes in the Pantanal's water flow dynamics[7], which show a current reality: in 2024 the biome did not have its flood period and for six years it has been resisting frequent fires.

6 Roque FO, Ochoa-Quintero J, Ribeiro DB, Sugai LS, Costa-Pereira R, Lourival R, Bino G. Upland habitat loss as a threat to Pantanal wetlands. Conserv Biol. 2016 Oct;30(5):1131-4. doi: 10.1111/cobi.12713. Epub 2016 May 3. PMID: 26968573.

7 Thielen, D., Schuchmann, K-L., et al. Quo Vadis Pantanal? Expected precipitation extremes and drought dynamics from changing sea surface temperature. (2020). PLoS ONE 15(1). doi. org/10.1371/journal. pone.0227437

FIGURE 2

Land cover and land use of the BAP (plain and plateau) and transition between 1985 and 2022 (adapted from MapBiomas)

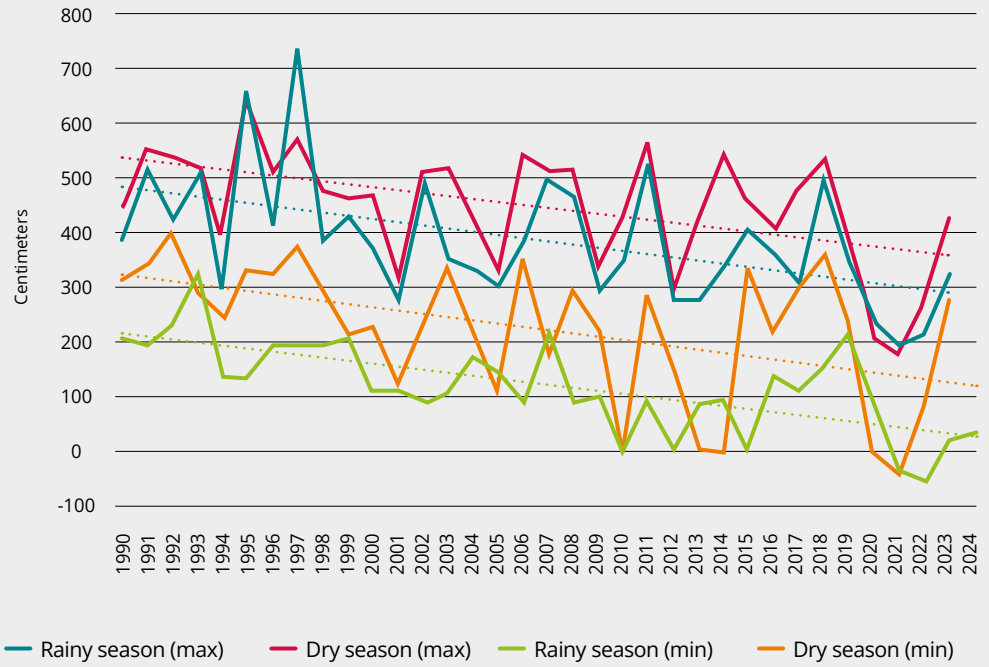


The history of the Pantanal's flood pulses is known from both local measurements and satellite image analyses, pointing to a common conclusion. From the records of the Ladário ruler, a reference for monitoring the level of the Paraguay River[8] **(Figure 3)**, the negative trend in the measurements of the maximum and minimum levels during both the flood season (October to April) and the dry season (May to September) highlights the decrease in flooding that has affected the Pantanal since 1990. In 2021, the rainy season high (1.8 m) and dry season low (1.7 m) were the lowest since the historic drought of the early 70s. All the months of 2021 and 2022 showed maximum levels lower than the average of the last 30 years, with minimum levels reaching 0.6 m below zero, even in the rainy season.

The level of the Paraguay River in the first five months of 2024 was, on average, 68% below the expected average for the period, which indicates another year of historic drought in the biome, with impacts on fish stocks, productivity and tourism activities[9].

FIGURE 3

Annual maximum and minimum measurements (in cm) of the Paraguay River recorded by the Ladário ruler from 1990 to 2024[10]



8 The Ladário station has an extensive historical data series dating back to 1900 and, in addition, more than 80% of the average flow of the Paraguay River is monitored at this location. It is located in the navigable region of the river, which is important for the flow of minerals, making it a strategic point for monitoring the water regime of the BAP.

9 Galdino S, Vieira LM, Oliveira H, Cardoso EL (2002) Impactos da agropecuária nos planaltos sobre o regime hidrológico do Pantanal. Corumbá: EMBRAPA-CPAP. 6 p.

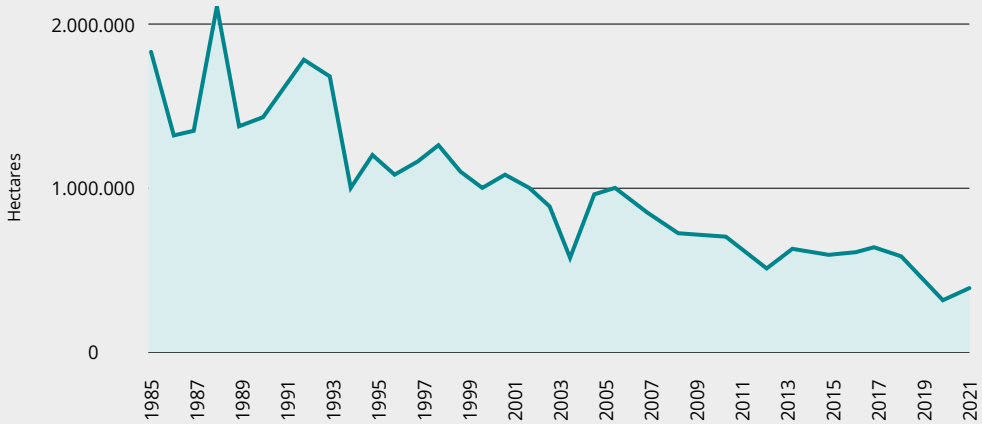
10 Data by hydrological year (October to September) from the Ladário station, provided by ANA (www.snirh.gov.br/hidroweb/serieshistoricas) and consistent with data from the Brazilian Navy (www.marinha.mil.br)

Another source of information on water surface and wetlands in the Pantanal since 1985 is provided by the MapBiomas Water Project, based on mosaics of Landsat satellite images[11], with a spatial resolution of 30 meters and a temporal resolution of 16 days. From 1985 to 2022, the Pantanal topped the ranking for water loss, with a shrinkage of around 82% of the area that remains flooded for 6 months or more **(Figure 4)**.

By combining the data on the maximum level of the Paraguay River in Ladário and the maximum and minimum water surface area mapped by MapBiomas, it is possible to show that floods have been getting smaller and smaller in recent years **(Figure 5)**. For example, in 2020 and 2021, the flooded area was below the already decreasing tendency, with the most flooded months less expressive than the driest months of the other years in the series.

FIGURE 4

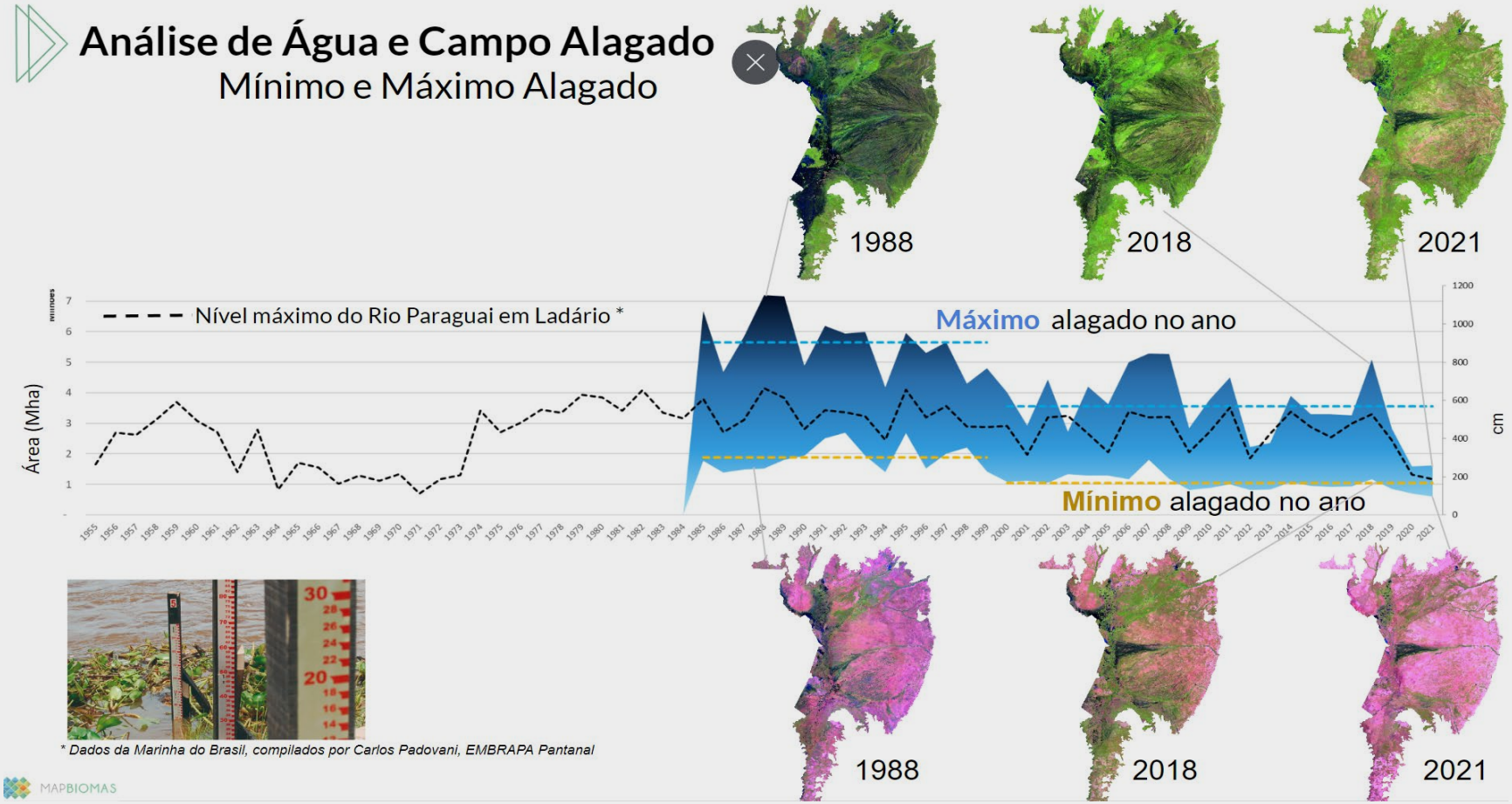
Temporal series of surface water in the Pantanal from 1985 to 2022 (adapted from MapBiomas Water)



11 Landsat 5, 7 e 8 - see methodology in https://amazonia.mapbiomas.org/pt/metodo-mapbiomas-agua/

FIGURE 5

Historical data series on the Pantanal's water regime



* Dados da Marinha do Brasil, compilados por Carlos Padovani, EMBRAPA Pantanal

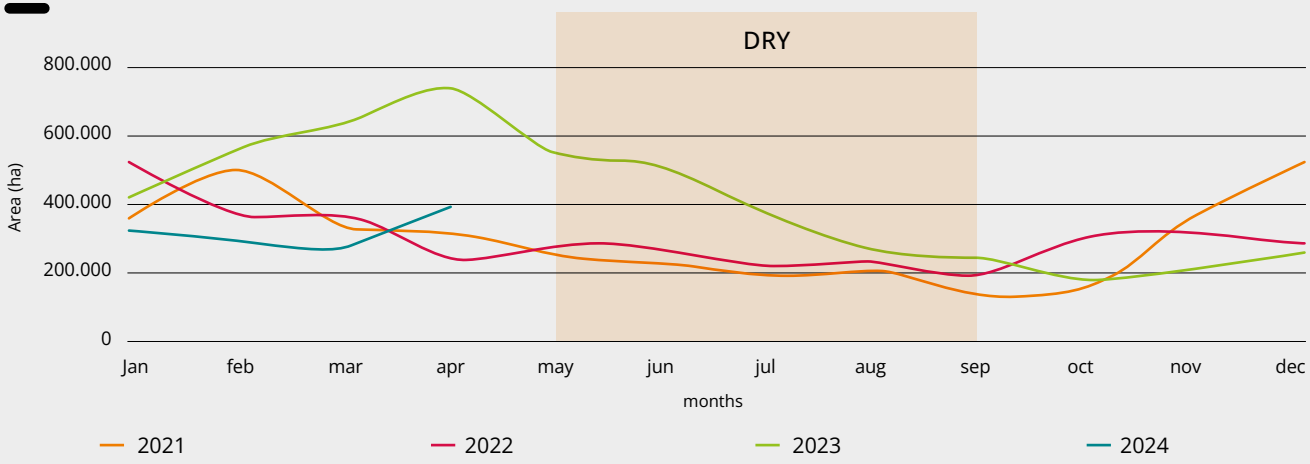
2 MAPPING THE WATERS OF THE PANTANAL WITH PLANET IMAGES

Due to the limits of the Landsat satellite's spatial and temporal resolution, the mapping of short-term events (15 days or less) and features smaller than 30m are limited. In view of this, one way to improve the monitoring of the Pantanal's flood pulses is to use Planet's satellites, which provide almost daily image coverage (every 26 hours), with a spatial resolution of 4 meters, which has enabled unprecedented, much more detailed monthly mapping for the period from 2021 to April 2024.

Among the full years observed, 2023 was the year of greatest flooding, with a maximum peak in April when around 660,000 hectares of water surface were recorded. The years 2021 and 2022, on the other hand, had a maximum water surface of just over 520,000 hectares during the full season, and an average flooded area during the dry season of between 318,000 and 344,000 hectares. However, the first months of 2024 present a worrying situation: the maximum value observed reached 430,000 hectares of water in April and, even more alarmingly, the average area covered by water from January to April, which was 400,000 hectares, is below the average observed during the dry season in years such as 2023 (440 hectares), which signals the absence of the expected behavior for the flood months **(Figure 6)**.

FIGURE 6

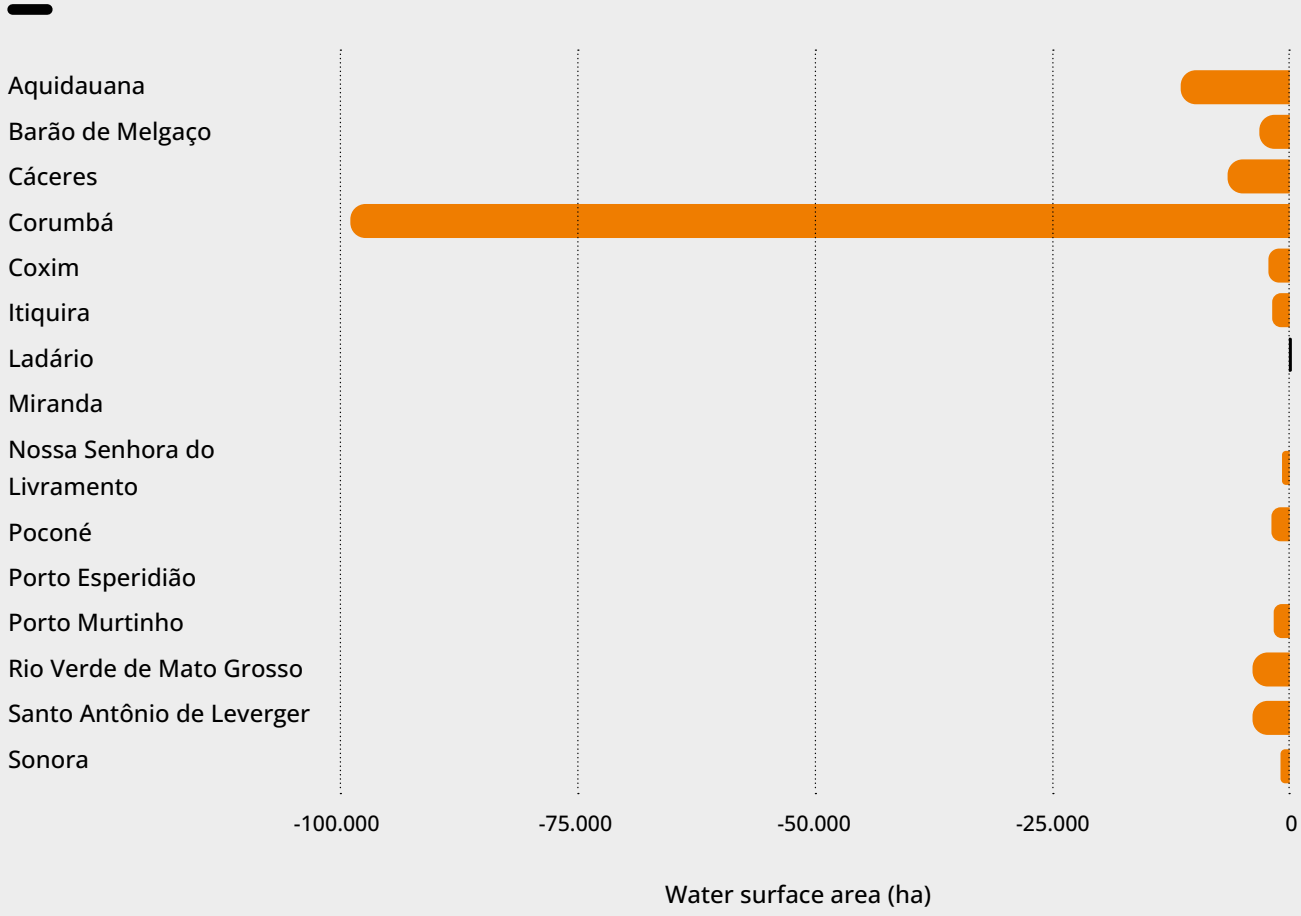
Monthly water area mapped from Planet satellite images from 2021 to 2024



The drought in the Pantanal directly affects the municipalities but with different magnitudes. Comparing the first quarter of 2024 and 2023, only the municipality of Ladário showed a gain in flooded area - just over 370 hectares. Two other municipalities, Miranda and Porto Esperidião, showed a variation of less than 30 hectares, maintaining the average area of water in the first quarter in both years **(Figure 7)**. This shows that in 2024 most municipalities will find themselves with less flooded area than the previous year.

FIGURE 7

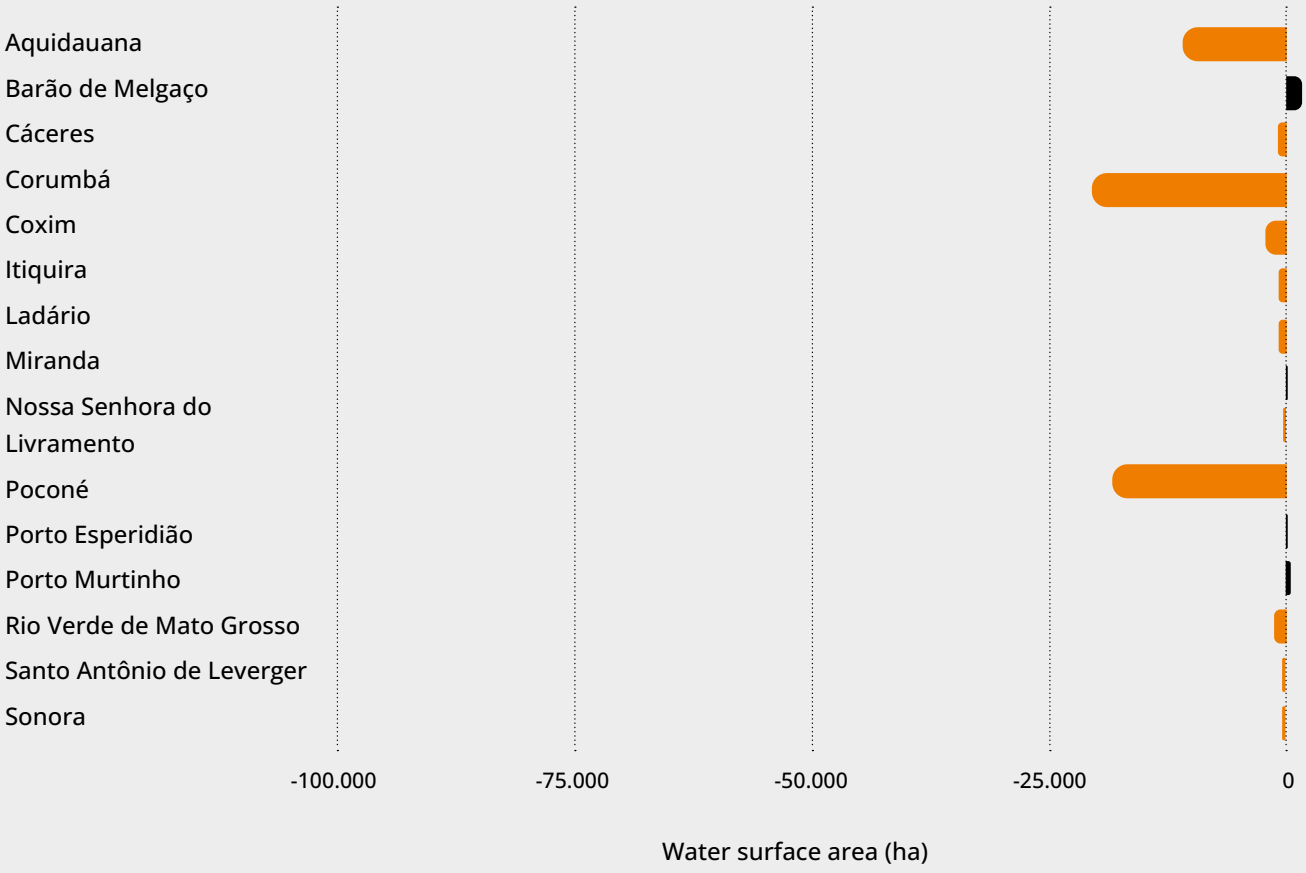
Comparison of water surface mapped from January to March in 2023 and 2024



Even when comparing the data for this same period with 2021, the year 2024 shows a reduction in the water surface. Corumbá, which is the largest municipality in the biome, with a total area of 6.5 million hectares, is also the one that has lost the most water surface area, around 20,400 hectares, followed by Poconé, which has seen a reduction of just over 18,205 hectares **(Figure 8)**. This comparison shows that for most municipalities, 2024 could be a drier year than 2021, the driest in the series analyzed.

FIGURE 8

Comparison of mapped water surface from January to March 2021 and 2024



The results presented here should serve as a warning of the urgent need for preventive and adaptive measures to the drought that could permanently change the Pantanal ecosystem, with drastic consequences for the richness and abundance of species of fauna and flora, as well as the local economy, which depends on the navigability of the rivers and the diversity of fauna, both for fishing and tourism. The reduction in river flows also leaves the country's energy production vulnerable, as it relies heavily on hydroelectric projects installed in the headwaters of the BAP[12].

12 Alternativas Energéticas Renováveis na Bacia do Alto Paraguai (BAP), WWF-Brazil (2020), available at https://www.wwf.org.br/?76082/Alternativas-Energeticas-Renovaveis-da-Bacia-do-Alto-Paraguai-BAP

WARNING OF THE URGENT NEED FOR PREVENTIVE AND ADAPTIVE MEASURES TO THE DROUGHT

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3 CONCLUSION

Water surface mapping using Planet images adds innovative detail to the analysis of the hydrological cycle of the Upper Paraguay river basin, especially for monitoring flood pulses in the Pantanal and distinguishing flooded and floodable areas. The unprecedented and recent results warn and anticipate the severity of the water crisis in the biome, given that the first quarter of 2024 was one of the driest ever recorded, with smaller areas than those observed in the previous year's dry season. Only one of the 15 Pantanal municipalities did not show a reduction in water surface area in 2024, compared to 2021, when the Pantanal had almost 30% of its entire area burned by fires resulting from the drought. This situation has had a high level of notoriety, both nationally and internationally, which has shown the disproportionate impacts on regional biodiversity.

Understanding the relationship between anthropogenic activities, climate change and the water cycle in the BAP is crucial to the development of action plans capable of raising awareness among the population and decision-makers. We can only talk about a conserved and sustainable Pantanal if we focus our efforts on conserving and restoring the landscape, as well as the ecosystem services provided by the Pantanal Headwaters region.

It is essential that Nature-Based Solutions and actions to prevent and adapt to extreme events, especially droughts and high temperatures, are implemented throughout the territory of the Upper Paraguay river basin, in order to safeguard life and avoid permanent socio-environmental damage.

THE UNPRECEDENTED AND RECENT RESULTS WARN AND ANTICIPATE THE SEVERITY OF THE WATER CRISIS IN THE PANTANAL

4 RECOMMENDATIONS

Define **CLIMATE CHANGE ADAPTATION** actions for the BAP, in preparation for increasingly frequent extreme events.

Mapping the threats that cause **THE GREATEST IMPACTS ON THE PANTANAL'S WATER BODIES**, especially considering the dynamics in the headwater regions.

Structure and implement communication plans to **DISSEMINATE AND RAISE PUBLIC AWARENESS OF THE IMPORTANCE OF THE PANTANAL HEADWATERS** and the Pantanal, a World Natural Heritage Site, in guaranteeing the survival of its biodiversity, natural resources and traditional populations.

Strengthen and expand **PUBLIC POLICIES** to curb deforestation.

Restore **PERMANENT PROTECTION AREAS** (PPAs) in the headwaters in order to improve water infiltration and reduce soil erosion and river silting, increasing the quality and quantity of water in both the plateau and the plain.

Map the **RISK OF FIRE AND SUPPORT RAPID RESPONSE SYSTEMS FOR FIRES**, by strengthening and structuring volunteer and official brigades, especially around areas of importance for biodiversity.

Map human exposure to drought and anticipate **EMERGENCY PLANS FOR THE CONSTRUCTION OF CISTERNS**, especially for the most vulnerable population.

Support the valorization of communities, landowners and the productive sector that develop good practices and scale up **SUSTAINABLE PRODUCTIVE ACTIONS** in the landscape (e.g., pasture recovery, topographical interventions and productive restoration), through measures such as tax incentives, expanding the network of conserved areas and promoting technologies and innovation to strengthen the sustainability agenda.

WWF-BRAZIL

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TECHNICAL NOTE

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