



Upland habitat loss as a threat to Pantanal wetlands

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The fate of Pantanal, one of the world's largest, most pristine and diverse wetlands, stands in the balance. The most recent (2014) and comprehensive land-cover change assessment of the upper Paraguay River Basin (UPRB), comprising both lowlands (Pantanal floodplain) and their surrounding upland savannas (Cerrado plateaus), shows the extent of decline of native vegetation (Fig. 1). Around 80% of the Pantanal floodplain native vegetation remains (Fig. 1), and over 60% of its Cerrado plateaus have been converted into pasture and croplands (SOS-Pantanal et al. 2015). The most worrying aspect is the fast rate of land clearing during the last 30 years (Supporting Information). In fact, the Cerrado is experiencing higher native vegetation conversion rates than Amazon and Atlantic Forest ecosystems in recent years but is still largely unprotected (Overbeck et al. 2015).

Biodiversity loss in the UPRB has been caused by a plethora of human activities, including elimination of native vegetation via damming in the headwaters and channelization of the Paraguay River channel on the floodplain, burning to clear vegetation, unsustainable fishing, water pollution, river-flow modification, unsustainable tourism, and invasive species (e.g., Alho & Sabino 2011; de Sousa Jr et al. 2011; Junk et al. 2011). We argue that a new viewpoint based on landscape thresholds should be applied to predict biodiversity loss in the UPRB. We suggest prompt actions to avoid crossing critical thresholds of vegetation loss in the uplands to prevent collapse of biodiversity and ecosystem functioning of the Pantanal wetlands. Our approach is consistent with 2 predominant characteristics of the UPRB that

make the system particularly sensitive to regional tipping points (Brook et al. 2013): high spatial homogeneity in drivers of habitat loss (Supporting Information) and tight functional and ecological interdependency between lowlands and Cerrado uplands.

We measured the amount of native vegetation in each of the 4546 planning units that comprise the UPRB and found that in 60% of them, <40% of native vegetation remains (Fig. 2). The native vegetation deficit was severe and widely distributed across the plateau, which is consistent with spatial homogeneity of vegetation-loss drivers (Supporting Information). Given that the Forest Act (FA) allows Cerrado ecosystem conversions of up to 80% of each property, an additional 12.8% of natural vegetation cover could be legally converted to planted pasture or crops (Brazilian Forest Act 2012; Soares-Filho et al. 2014).

If historic (1976–2008) trends of land conversion in the UPRB continue (business as usual scenario in combination with weak enforcement), a complete loss of native vegetation can be expected by 2029 in the plateau and by 2045 in the floodplain (Silva et al. 2011). Considering that 1087 km² of land was converted in the plateaus from 2012 to 2014 (SOS-Pantanal et al. 2015), we posit that the plateau's native vegetation is approaching critical levels of degradation. Conversions of over 60% of native tropical ecosystems have led to abrupt species loss due to exponential increase in the distance between forest fragments, which has affected survival and dispersal among subpopulations (Banks-Leite et al. 2014; Ochoa-Quintero et al. 2015).

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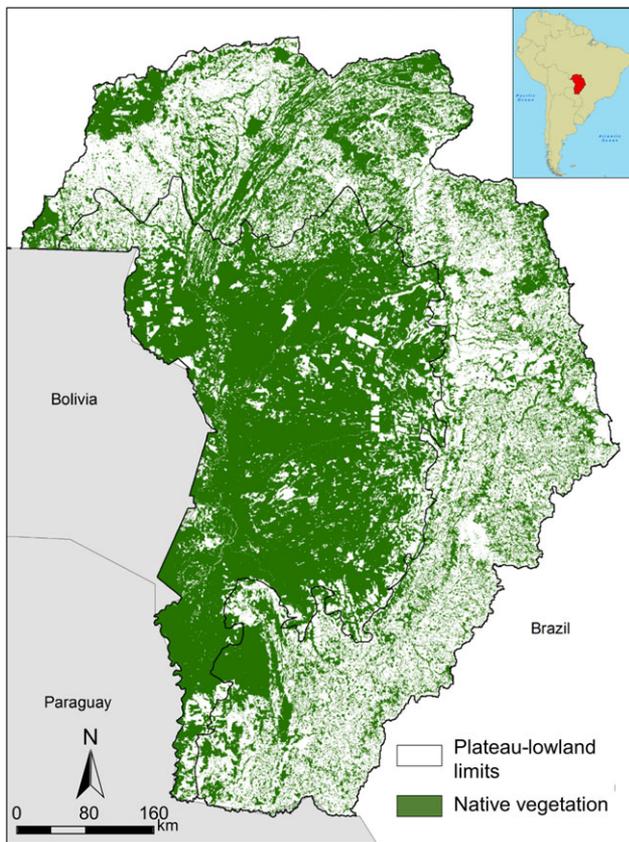


Figure 1. Upper Paraguay River Basin: remaining native vegetation on the Pantanal lowland and its surrounding savanna (Pantanal plateau).

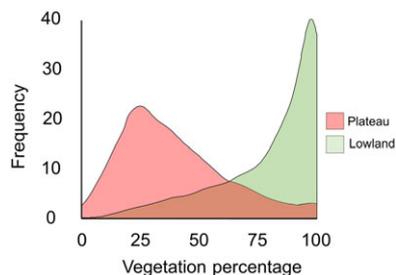


Figure 2. Frequency distribution of native vegetation within landscapes on the Pantanal lowland and on its surrounding plateau savanna. Each landscape represents a hexagonal planning unit of 10,000 ha (Supporting Information).

Despite an incomplete understanding of the complex hydrology of the UPRB (Hamilton 2002), there is sufficient evidence that land conversion in the plateau's headwaters is affecting the hydrodynamics of UPRB (Bergier 2013). Unsustainable agroecosystems in the plateau are reducing the catchment's water storage and buffering capacity and have resulted in increased sediment runoff of up to 191% and increased water discharge of up to

82% in the lowlands, the result of which is significant alterations in flood dynamics, ecosystem functioning, and ecosystem services (Bergier 2013).

The way in which impacts of land-use changes on the plateau are transferred to the Pantanal wetlands through hydrodynamic processes is explained by the phenomenon of river avulsion. This phenomenon is characterized by the diversion of flow from an aquatic channel onto the floodplain, eventually resulting in new channel belts, as reported for alluvial megafan systems. The Taquari megafan, one of the largest (50,000 km²) and most threatened in the world, is a river network that drains the plateau toward the lowlands and has specific intersection nodes that control flow direction. The avulsion in Taquari occurs during river discharge events with a magnitude close to an avulsion threshold, which is related to the degree of sedimentation and a reduction in the capacity of the channel flow downstream (Assine 2005). The intensification of erosion caused by cattle ranching and agriculture in the plateau over the last 30 years has accelerated the avulsion processes, and avulsion thresholds have been crossed more frequently. These events have affected the spatial arrangement of wetland vegetation and affected biodiversity dynamics, ecosystem processes, and the local economy (Assine 2005).

Changes in intensity and duration of the flood regime impact the distribution, areal extent, and seasonal persistence of wetlands, grasslands, and forests and have already altered biodiversity patterns and species distributions in the Pantanal (Junk et al. 2011). These changes can induce sharp transitions between vegetation communities (e.g., seral stages), such as grasslands, wetlands, and forested areas (Lourival et al. 2011), typical of the nonlinear dynamics of savannah-forest systems (Hirota et al. 2011). Landscape changes in uplands may also have direct impacts on seasonal animal movements between plateau and lowlands. The UPRB supports approximately 300 fish species, including 12 species of economically important migratory fish inhabiting lowlands, which use the main river channels to migrate to headwaters for spawning, a phenomena called *piracema*. Forest degradation in the headwaters alters the input of sediments and coarse organic matter in aquatic environments and jeopardizes fish migration routes and habitat quality (Resende 2003). Bird migration also illustrates the ecological connectivity between uplands and lowlands. At least 41 migratory birds occurring on the floodplain use Cerrado areas in their migratory routes. Land-use changes on the plateau affect food availability for migrants, such as 2 endangered granivorous species of *Sporophila* that depend on seeds of native plants in both the plateau and lowlands (Nunes & Tomas 2004).

We argue that urgent government action is needed to avoid additional natural vegetation conversion and probable collapse of ecosystems in the Pantanal. One

opportunity lies in environmental compliance and regulation at the state-governance level because offsets from land conversion are legally restricted to the same biome. Recognition of the UPRB as a management unit for compliance and offsetting would allow compensating vegetation deficits between the Cerrado and Pantanal as interdependent parts of the same basin. Considering the UPRB a single unit would require compromise and collaborative initiatives among states, and such initiatives are particularly critical because the Pantanal is a transnational wetland. An intrabasin offsetting strategy could reduce the economic pressure on existing native vegetation, adding value to the remaining Cerrado and wetlands through offsetting. Such a regulation is biogeographically and ecologically critical given the wetland hydrology is associated with contiguous catchment areas.

Despite recognition of the Pantanal as a wetland of global importance (UNESCO Biosphere Reserve, 3 RAMSAR sites, and a cluster of 4 protected areas that comprise a World Heritage site), the state of Mato Grosso do Sul, which contains 65% of the Brazilian Pantanal, has enacted a decree (Decreto no. 14.273, de 8 de Outubro de 2015) that allows habitat conversion in lowlands (i.e., up to 60% of grassland habitats and 50% of Cerrado on private property) without consulting neighboring states and countries and without considering the National Heritage status, conferred by the Brazilian Constitution, of the area. This decision contradicts the idea of wise use proposed by the RAMSAR Convention on Wetlands, of which Brazil is a signatory.

Currently, <4% of the plateau is under no-take reserves, a low proportion considering the Aichi 17% representation targets for terrestrial biodiversity. Protected areas are the most effective strategy to safeguard biodiversity, particularly when following a systematic planning approach that considers ecosystem dynamics and functioning (Lourival et al. 2011). Achieving a comprehensive, representative, and adequate protected-areas system in the UPRB requires substantial commitment and government involvement. At the federal and state levels, several priority-setting exercises for the entire UPRB prioritized the need to conserve critical areas for ecological connectivity. However, public reserves are still underrepresenting the regional biodiversity.

We recommend strategies to reverse the potential collapse of biodiversity, particularly through halting deforestation, minimizing damming for electricity production, and encouraging socioeconomic incentives for restoration and protected area creation. Applying the FA regulatory framework will require additional adjustments to ensure fairness in the offsetting compensation schemes. The adjustments should encourage compensation and restoration of environmental debts from other areas of Cerrado while creating incentives for landowners from other states to invest in restoration of the integrity of this globally important basin. More importantly, state-level

policies should go beyond the legal 20% requirements for reserve set-asides and set targets for wetland integrity in the lowlands while maintaining native vegetation above potential tipping thresholds in the plateau. These strategies can be reinforced through effective environmental governance at the basin level. Improving conservation efforts across the entire basin and enhancing connectivity between lowlands and Cerrado uplands are urgently needed to maintain the Pantanal's status as one of the world's most pristine wetlands.

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Supporting Information

A historical view of land-use changes in the UPRB over the last 30 years (Appendix S1), land-cover change and a vegetation map of UPRB (Appendix S2), and an analysis of the spatial structure of the proportion of natural vegetation across the plateau's planning units with a generalized additive model (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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