Programa de Pós Graduação em Ecologia e Conservação
Instituto de Biociências da Universidade Federal de Mato Grosso Do Sul

Land use scenarios for the Pantanal: Implications for conservation, management and ecosystem functioning

Angélica Guerra

UFMS
Campo Grande
Novembro de 2019

Land use scenarios for the Pantanal: Implications for conservation, management and ecosystem functioning

Cenários de uso da terra no Pantanal: implicações para conservação, manejo e funcionamento do ecossistema

Angélica Guerra

Tese apresentada como requisito para a obtenção do título de **Doutora em Ecologia**, pelo Programa de Pós Graduação em Ecologia e Conservação, Universidade Federal de Mato Grosso do Sul.

Orientador: Rafael Dettogni Guariento
Co-orientadora: Letícia Couto Garcia
Co-orientador: José Manuel Ochoa-Quintero

Banca avaliadora

Dr. Arnildo Pott
Universidade Federal de Mato Grosso do Sul - UFMS

Dr._Maurício de Almeida Gomes
Universidade Federal de Mato Grosso do Sul - UFMS

Dra. Aliny Patrícia Frauzino Pires
Universidade Estadual do Rio de Janeiro - UERJ

Dra. Cátia Urbanetz
Embrapa Pantanal

Salina do Coração na Fazenda Barranco Alto, Pantanal da Nhecolândia
Foto: Lydia Möcklinghoff

"O passado está morto, jamais poderá ser recriado.
O que fizemos foi reconstruuir o passado, ou pelo menos uma versão dele.
E eu afirmo que podemos fazer uma versão melhor".
"Melhor do que o real?"
"Por que não?"

Michael Crichton, *Jurassic Park*

À minha avó Conceição (in memoriam), que se faz presente em todos os dias da minha vida. Sei que de seu lugar olha por mim, e acompanha cada passo meu.

Agradecimentos

Estes foram, sem dúvida, os quatro anos mais intensos da minha vida. Não apenas pelas dificuldades de me aventurar em uma nova área, mas também por diversos obstáculos pessoais. E eu não conseguiria ter finalizado esta etapa sem o apoio de pessoas muito importantes para mim, à quem eu gostaria muito de agradecer.

Aos meus pais, por sempre me apoiarem e nunca me deixarem desistir dos meus objetivos. Obrigada por serem meu alicerce, meu motivo de orgulho e por sempre me estenderem a mão!

Às minhas irmãs, Naiara e Ana Paula, por sempre estarem ao meu lado e me aconselharem quando eu preciso. Não importa a dificuldade que a gente passe, como um tripé, vamos estar sempre juntas, uma fortalecendo a outra.

À Letícia Couto Garcia, que me permitiu, além da tese, trabalhar em diversos projetos envolvendo restauração ecológica, contribuindo muito para minha formação e para um novo olhar dentro da pesquisa. Obrigada pela confiança, apoio, incentivo, amizade, e pelos infinitos ensinamentos.

Ao José Ochoa-Quintero, que me prepôs este projeto e confiou que eu seria capaz de executá-lo, mesmo sendo totalmente novo para mim. Obrigada pela confiança!

Ao Rafael Guariento, pela orientação, conselhos, incentivo e principalmente por todo apoio emocinal durante esses quase quatro anos.

Ao Paulo Tarso, por ter aceito participar do projeto e por não ter medido esforços para me ajudar. Obrigada pelas ideias, discussões, sugestões e pela confiança!

À Isabel Rosa, que teve um papel fundamental neste trabalho. Obrigada por toda ajuda com as análises, pelos ensinamentos e pela prontidão em sempre esclarecer todas as minhas dúvidas.

Ao Fábio Roque, por me despertar um novo olhar sobre a Ecologia da Conservação, e por todas as oportunidades que tem confiado à mim. Obrigada pela confiança e por, além de professor, ser um amigo.

Aos amigos do LEI – Laboratório de Ecologia da Intervenção, pela amizade e parceria. Em especial à Letícia Koutchin, por ter se tornado uma grande amiga e parceira de trabalhos!

Aos amigos de anos, àqueles que sempre estão comigo, Bruno, Camila Silveira, Aline, Neto, Gui, João Pedro, Nina. Obrigada pela amizade de vocês!

Aos amigos do PPGEC, pelos momentos compartilhados, principalmente durante o EcoPan2017.

Ao pessoal do IIS – Instituto Internacional para Sustentabilidade, pelo acolhimento, ensinamentos e por terem me recebido tão bem nos dois meses que passei no Rio com vocês!

Ao Fábio Júnior, pela dedicação e disponibilidade.

À Fundect, pela concessão da bolsa de estudos.

Á todas as pessoas que colaboraram para a realização deste trabalho, diretamente ou indiretamente, meus sinceros agradecimentos!

Table of Contents

General abstract 01
Resumo geral 02
General Introduction...03
References 05

Chapter 1: Drivers and projections of vegetation loss in the Pantanal and neighbouring ecosystems …………………………………………………………………..08
Abstract 08
Introduction 09
Methods...12
Study Site..12
Data sources..13
Model…..15
Results 19
Drivers of native vegetation loss...19
Projection of native vegetation loss...21
Arc of native vegetation loss...23
Discussion 24
Drivers of native vegetation loss...24
Projection of native vegetation loss...28
Arc of native vegetation loss...29
References 32
Supporting Information..42

Chapter 2: The importance of Legal Reserves for protecting the Pantanal biome and preventing agricultural losses...50
Abstract 50
Introduction 52
Methods 54
Setting up the scenarios..54
Modeling the native vegetation loss...57
Soil loss estimation 57
Sediment Delivery Ratio (SDR) 62
Economic cost of soil erosion..62
Results 63
Loss of native vegetation..63
Soil loss and economic costs..66
Sediment yield..70
Discussion 70
Loss of native vegetation..70
Soil loss, economic costs and sediment yield..71
Conclusion 75
References 76
Supporting Information..84

Final Considerations..87
References 90

General abstract

Scenario building is a fundamental tool for understanding how nature will respond to different paths of human development and public policy. In addition, by future projections of important ecosystems such as the Pantanal, one of the largest wetlands in the world, and considered a hotspot for ecosystem services, can help shape public policies to mitigate the impacts of human activity. Therefore, in this thesis we use scenarios to evaluate how different environmental laws may impact vegetation loss. In Chapter 1, we use a spatially explicit model to identify drivers of vegetation loss in the Upper Paraguay River Basin (UPRB) plateau and lowland and to project vegetation loss by 2050 according to the land use trend of the (2008 to 2016) and considering the Legal Reserve rates provided for the Native Vegetation Protection Law (NVPL), popularly know as "New Forest Code." We have identified that vegetation loss drivers are different between the plateau and the lowland and that more than 14,000 km² of native vegetation in the UPRB is expected to be lost by 2050. In addition, we identified a spatial pattern into an Arc of vegetation loss in the Pantanal. The identification of the arc is extremely important for emergency public policies that can be implemented in this area, as it presents a rapid conversion. In Chapter 2, we use the same model used in Chapter 1 to project vegetation loss in UPRB under different legal reserve rates required by environmental laws or bills, as follows: (i) BAU: Business as usual, which considers existing laws: the NVPL and the Mato Grosso do Sul State Decree (14,273 of 2015); (ii) LRE: extinction of the Legal Reserve (LR) owing to the recently proposed bill; (iii) LR50: considers the proposal of 50% of LR for the Pantanal; and (iv) LR80: we suggest an 80% LR proposal for the Pantanal lowlands and 35% for the Pantanal plateau. In addition, we evaluated how each scenario of vegetation loss would affect soil erosion, sediment yield, and soil nutrient replacement costs. The LRE scenario would generate loss of over 30,000 km² of native vegetation in the Pantanal. Scenarios LR80 and LR50 may prevent the loss of 3% and 2% of native vegetation, respectively, compared with BAU scenario. Reducing RL rates will increase soil erosion and sediment production in the Pantanal by up to 7% and 10%, respectively, where over 90% of the sediment transported to the Pantanal lowland coming from the plateau. The LR80 scenario projects a reduction in soil nutrient replacement costs by 10% compared with BAU, while the LR50 scenario decreases by 1.5%. The LRE scenario predicts an 8% increase in soil nutrient replacement costs compared with BAU. Our results show the importance of the Legal Reserve in the Pantanal to avoid losses of ecosystem services such as soil quality, and also the importance of LR for agriculture.

Resumo geral

A construção de cenários é uma ferramenta fundamental para entendermos como a natureza responderá a diferentes caminhos do desenvolvimento humano e de políticas públicas. Além disso, entender como será o futuro de ecossistemas importantes como o Pantanal, uma das maiores áreas úmidas do mundo e considerada *hotspot* de serviços ecossistêmicos, pode contribuir para formulação de políticas públicas que diminuam ou amenizem os impactos da atividade humana. Por isso, nesta tese usamos cenários para avaliar como diferentes leis ambientais podem impactar a perda de vegetação. No Capítulo 1, usamos um modelo espacialmente explícito para identificar fatores de perda de vegetação no planalto e na planície da Bacia do Alto Paraguai (UPRB) e projetar a perda de vegetação até 2050, de acordo com a tendência de uso da terra (2008 a 2016) e considerando as taxas de Reserva Legal previstas na Lei de Proteção à Vegetação Nativa (NVPL), popularmente conhecida como "Novo Código Florestal". Identificamos que os fatores de perda de vegetação são diferentes entre o planalto e a planície e que mais de 14.000 km² de vegetação nativa espera-se que a UPRB se perca em 2050. Além disso, identificamos um Arco de perda de vegetação no Pantanal. A identificação do arco é de extrema importância para que políticas públicas emergenciais sejam implementadas nesta área, por apresentar rápida conversão. No capítulo 2 usamos o mesmo modelo usado no capítulo 1 para projetar a perda de vegetação na BAP sob diferentes taxas de reserva legal previstas em leis ambientais ou projetos de lei. (i) BAU: *Business as usual*, que considera as leis existentes: a Lei de Proteção à Vegetação Nativa (NVPL) e o Decreto Estadual de Mato Grosso do Sul (14.273 de 2015); (ii) LRE: extinção da Reserva Legal (LR) devido ao projeto de lei recentemente proposto; (iii) LR50: considera a proposta de 50% da LR para o Pantanal; e (iv) LR80: sugerimos uma proposta de 80% da LR para as planícies do Pantanal e 35% para o planalto do Pantanal. Além disso, avaliamos como cada cenário de perda de vegetação afetaria a erosão do solo, exportação de sedimentos e custos de reposição de nutrientes do solo. O cenário LRE geraria perda de mais de 30.000 km² de vegetação nativa no Pantanal. Os cenários LR80 e LR50 podem impedir a perda de 3% e 2% de vegetação nativa, respectivamente, em comparação com o cenário da BAU. A redução das taxas de RL aumentará a erosão do solo e a produção de sedimentos no Pantanal em até 7% e 10%, respectivamente, onde mais de 90% dos sedimentos transportados para a planície pantaneira vieram do planalto. O cenário LR80 projeta uma redução nos custos de reposição de nutrientes do solo em 10% em comparação com o BAU, enquanto o cenário LR50 diminui em 1,5%. O cenário LRE prevê um aumento de 8% dos custos de reposição de nutrientes do solo quando comparado ao BAU. Nossos resultados mostram a importância da reserva legal no Pantanal para evitar perdas de serviços ecossistêmicos como a qualidade do solo, e também a importância para a agricultura.

General Introduction

The Pantanal is considered a hotspot of ecosystem services and is one of the largest wetlands on the planet (Constanza et al. 1997, Tomas et al. 2019). The biome is located in the Upper Paraguay River Basin (UPRB), which is formed by the lowland (Pantanal biome) and the plateau (Cerrado and Amazon biomes), where the river springs are located. The lowland is marked by an annual flood pulse caused by the Paraguay River and its tributaries (Junk et al. 1989, Junk 1993, 1999). It is a very heterogeneous environment and presents different formations such as wetlands, grasslands, forest and savannah (MapBiomas 2017, http://mapbiomas.org). This heterogeneity of environments provides habitat for a large number of species, and the result is the rich biodiversity found in the biome: 174 mammal species, 580 birds, 113 reptiles (177 in the basin), 57 amphibians, 271 fish, more than 2,000 plants (3,400 in the basin) (Tomas et al. 2019). In addition to being known as a refuge for migratory species, it receives a large number of waterfowl every year (Antas et al. 1994).

While the Pantanal lowland is the most preserved biome in Brazil, with over 80% native vegetation, the plateau has undergone intense land use conversion over the past 30 years, with only 39% native vegetation remaining (Roque et al. 2016). The conversions are mainly caused by livestock and agriculture activities, which are more intense on the plateau, to the lowland flooding pulse that prevents crop planting throughout the year (SOS Pantanal et al. 2017).

Plateau and lowland show great functional interdependence (Assine 2005), and all activities performed on the plateau have direct consequences on the lowland (Roque et al. 2016). Intense land use conversions on the plateau have caused significant changes in lowland dynamics, which has endangered the entire dynamics of this biome (SOS Pantanal et al. 2017). The biggest example one is how the change from natural areas to plateau agriculture caused soil erosion and siltation of rivers, altering their flows and hydrological regimes in the Pantanal, as has been observed in the Alto Taquari basin (Assine 2005, Galdino et al. 2006). Increasingly frequent episodes of river siltation, causing so-called "arrombados", cause flooding of areas that were not previously flooded, resulting on death of animals and leaving people homeless (Galdino et al. 2006). In addition, it endangers the ecosystem services provided by the biome, such as water availability, carbon sequestration, and biodiversity (Reyers et al. 2009).

Simulated scenarios are important tools for generating future projections of how vegetation loss and other landscape changes may affect ecosystem services (Rosa et al. 2017). In addition, to being efficient in the sense that they can be used by the government for decision-making and law-making (Ferrier et al. 2016). Biodiversity loss emerge from interactions between drivers operating across a wide range of scales, spatial and temporal. Consequences of these changes, such as loss of ecosystem services supply, also occur across multiple scales. However, recent Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) methodological assessment of scenarios and models of biodiversity and ecosystem services showed that scenarios used in global assessments rarely integrate values and processes from sub-regional scales (Rosa et al. 2017). In addition, scenarios-based simulations usually consider nature as the endpoint of the conservation agenda, but there is little hope that this approach will inform the more ambitious and longer-term component of our (i.e., society) relationship with nature at the center of scenario development, and addresses the full range of social–ecological feedbacks. Scenarios developed by this long-term endeavor will underpin future rounds of IPBES regional and global assessments. In this context this thesis is structured into two chapters:

In Chapter 1 we use a spatially explicit model to identify drivers of native vegetation loss in the UPRB and to project vegetation loss by 2050 considering the trends of recent years (2008-2016) and the full implementation of the "New Forest Code". Our goal was to identify areas under greater threat of conversion and to identify potential geographical patterns of land use change (e.g. Arc) in this biome, thus helping to guide and inform targeted conservation actions. In Chapter 2, we use the spatially explicit model used in Chapter 1 to generate different scenarios of vegetation loss at different Legal Reserve rates. Our goal was to evaluate how Legal Reserve affects, in addition to vegetation loss, soil erosion and sediment production and to evaluate the cost of soil nutrient replacement in agriculture and livestock areas.

We hope that the results of this thesis can be used in the elaboration of public policies on land use in the Pantanal and in wetlands in general, helping in the decision making of the public power.

References

Antas, P.T.Z. 1994. Migration and other movements among the lower Paraná River valley wetlands, Argentina, and the south Brazil/Pantanal wetlands. Bird Conservation International, 4, 181-190.

Assine, M. L. 2005. River avulsions on the Taquari megafan, Pantanal wetland, Brazil. Geomorphology, 70, 357–371. http://dx.doi.org/10.1016/j.geomorph.2005.02.013

Costanza, R., d' Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., … van den Belt, M. 1997. The value of the world's ecosystem services and natural capital. Nature, 387(6630), 253–260. https://doi.org/10.1016/S0921-

8009(98)00020-2

Ferrier, S., Ninan, K. N., Leadley, P., Alkemade, R., Acosta, L. A., Akçakaya, H. R., Brotons, L., Cheung, W. W. L., Christensen, V., Harhash, K. A., Kabubo-Mariara, J., Lundquist, C., Obersteiner, M., Pereira, H. M., Peterson, G., Pichs-Madruga, R., Ravindranath, N., Rondinini, C. Wintle, B. A. 2016. (eds) The methodological assessment report on scenarios and models of biodiversity and ecosystem services (IPBES).

Galdino, S., Vieira, L. M. & Pelegrin, L. A. 2006. Impactos ambientais e socioeconômicos na Bacia do Rio Taquari – Pantanal. Corumbá: Embrapa Pantanal.

Junk, W. J. 1993. Wetlands of tropical South America. Pages 679–739 Wetlands of the world: Inventory, ecology and management Volume I. Springer Netherlands, Dordrecht.

Junk, W. J. 1999. The flood pulse concept of large rivers: learning from the tropics. River Systems.

Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood-pulse concept in river-floodplain systems.

Reyers, B., P. J. O'Farrell, R. M. Cowling, B. N. Egoh, D. C. Le Maitre and J. H. J. Vlok 2009. Ecosystem services, land-cover change, and stakeholders: finding a sustainable foothold for a semiarid biodiversity hotspot. Ecology and Society, 14(1), 38. http://www.ecologyandsociety.org/vol14/iss1/art38/

Roque, F. O., Ochoa-Quintero, J., Ribeiro, D. B., Sugai, L. S. M., Costa-Pereira, R., Lourival, R., Bino G. 2016. Upland habitat loss as a threat to Pantanal wetlands. Conservation Biology, 30(5), 1131-1134. https://doi.org/10.1111/cobi.12713

Rosa, I. M. D. et al. 2017. Multiscale scenarios for nature futures. Nature Ecology & Evolution, 10, 1416–1419. https://doi.org/10.1038/s41559-017-0273-9

SOS-Pantanal, WWF-Brasil, Conservation-International, ECOA, Fundación-AVINA. 2017. Monitoramento das alterações da cobertura vegetal e uso do solo na Bacia do Alto Paraguai Porção Brasileira-Período de análise: 2016 a 2017. Corumbá: Embrapa Pantanal.

Tomas, W. M., et al. 2019. Sustainability Agenda for the Pantanal Wetland: Perspectives on a Collaborative Interface for Science, Policy, and Decision-Making. Tropical Conservation Science 12: 1–30.

Chapter 1

Drivers and projections of vegetation loss in the Pantanal and neighbouring ecosystems

Abstract

Modeling scenarios can help identify drivers of and potential changes in land use, particularly in rapidly changing landscapes such as the tropics. One of the places where most of the recent anthropogenic land use changes have been occurring is the so-called "Arc of Deforestation" of the Amazon, where several scenarios have been constructed. Such modeling scenarios, however, have been implemented less frequently in wetland areas, but these are also undergoing rapid change. An example is the Pantanal, one of the largest wetlands on the planet located in the Upper Paraguay River Basin (UPRB), which is formed by the lowland (Pantanal) and the plateau (Cerrado and Amazon where the spring-fed rivers are). We used a spatially explicit model to identify drivers of vegetation loss in the Pantanal and surrounding area (UPRB) and estimated potential vegetation loss for the next 30 years. The model is probabilistic and considers that vegetation loss is contagious, so that the local rate of deforestation increases over time if adjacent sites are deforested, also taking into account the drivers identified in those locations. Our study is the first to simulate vegetation loss at property-scale, over 20,000 properties, for the entire UPRB in Brazil, taking into account the relationship between the plateau, where headwaters are located, and the lowland, where flooded-areas are concentrated. The drivers of vegetation loss identified for the lowland (distance to roads and rivers and elevation) differed from those for the plateau (distance to cities), demonstrating the relevance of analyzing areas separately. The cumulative rate of native vegetation loss projected for 2050 was 3% for the lowland and 10% for the plateau, representing losses of 6,045 km^2 and of native vegetation area decreasing from 87% to 83% and 7,960 km^2 from 39% to 35% respectively by 2050, if changes continue at the same pace and if the environmental legislation is followed. The projected vegetation loss in the UPRB forms a geographical arc, very similar to that observed in the Amazon, from the plateau into the lowland. The arc is directly related to areas with no or low flooding frequency because they are suitable for agriculture. The identification of this arc of vegetation loss calls for urgent conservation policies for this wetland and new perspectives for management.

Introduction

Scenarios, produced using simulation models, are important tools for predicting how nature might be impacted by different patterns of future human development and political choices, and projecting the resulting dynamics of land cover and land use change (LCLUC) (Ferrier et al., 2016; Rosa et al., 2017). Such scenarios can also guide attitudes, choices, and actions that increase the probability of realizing a desirable future (Bai et al., 2016). In Brazil, most of these scenario modeling exercises have targeted the Amazon, highlighting potential impacts of maintaining historical rates of deforestation on biodiversity (e.g., Laurance et al., 2001, Soares-Filho et al., 2006), and estimating the impacts of implementing policies to prevent deforestation (Rosa et al., 2013, Bradley et al., 2017). In general, the use of scenario modeling is more common for forested areas than for non-forest biomes, such as periodically flooded savanna, that face significant conversion (Zedler & Kercher, 2005; Reis et al., 2017; Hartig & Bennion, 2017). In addition, to our knowledge, vegetation loss at the property-level has yet to be considered for any tropical wetland.

Simulation models and analysis of historical LCLUC have contributed to identifying areas experiencing rapid transformations. A great example of this is the so-called 'Arc of Deforestation', located along the transition between the Amazon and the Cerrado (tropical savanna) biomes (Lathuillière et al., 2016), where the majority of anthropogenic land use change in South America has occurred. The identification of an arc of deforestation is related to both the current rate of transformation, which is faster in the arc than any other place, but also that will likely maintain a rapid rate of change in the coming years based on the modeling (Soares-Filho et al., 2006). Forest loss in the Amazon accounted for 41% of global forest loss (53 out of 129 Mha) from 1990 to 2015 (FAO, 2016), 70% of which was in the Legal Amazon in Brazil (36 Mha) (INPE, 2016). Other biomes within Brazil have also experienced significant LCLUC over the last few decades, such as the Cerrado (Spera et al., 2016) and the Pantanal (Roque et al., 2016), but have received fewer targeted conservation actions.

The Pantanal is a periodically flooded savanna (Junk et al., 2013), one of the most biodiversity-rich wetlands in the world (Junk et al., 2011), it is located within the Upper Paraguay River Basin (UPRB) and comprises a lowland area (Pantanal biome) and a plateau that includes the Pantanal and the surrounding Cerrado and Amazon biomes. It is also among the regions of Brazil that have experienced the greatest landscape change in recent years showing the need for improving public policies (SOS Pantanal et al., 2017, Tomas et al. 2019). Given the widely-expected near-future trend of agriculture expansion (Foley et al., 2005), there is an urgency to anticipate what this expansion might represent in terms of the future of this special biodiversity-rich biome (Junk et al., 2006) and an important area of multiple ecosystem services (ES) that is needed for global evaluation of ES monetization (Costanza et al., 1997; Davidson et al., 2019) in order to develop preventive conservation measures to minimize impacts.

Hence, scenario modeling can contribute to improve awareness and perception of future trends and problems related to land use change in the Pantanal, and thus inform decision-makers with public power, especially lawmakers, and in the private sector. Brazil has recently introduced several bills that represent environmental setbacks, such as the bill that provides for the extinction of the 'Legal Reserve' (PL 2,362/2019) which was withdrawn after popular pressure (Abessa et al., 2019, Kehoe et al., 2019; Zeidan, 2019, Lorran, 2019). Therefore, estimating the trends of vegetation loss and detecting their main drivers can support urgently-needed pleas to develop more environmentally-friendly policies and to help citizens communicate to policy-makers the need to avoid policies that further threaten the environment.

We used a published and validated spatially explicit model (Rosa et al., 2013) to initially identify the main drivers of vegetation loss in UPRB by considering the different dynamics of the plateau and lowland, owing to historically distinct land use and occupation, as well as the lowland flood pulse. Once main drivers of vegetation loss were identified, we used our model to generate projections of the probability of native vegetation loss by the year 2050 for the basin as a whole, and considering both the lowland and plateau separately. Our goal was to identify areas under greater threat of conversion and to identify potential geographical patterns of land use (e.g., Arc) in this biome, thus helping to guide and inform targeted conservation actions.

Methods

Study site

In Brazil, the Pantanal extends across the states of Mato Grosso and Mato Grosso do Sul, occupying 41% of the Upper Paraguay River Basin (UPRB). The basin includes three biomes: the Pantanal (lowland), which has 80% of its area flooded every year, the Cerrado and the Amazon, on the plateau where the spring-fed rivers are located (Fig. 1) (SOS Pantanal et al. 2017). The Pantanal is marked by an annual flood pulse that presents a great variation of time and extension due to the heterogeneity of environments (Nogueira et al., 2002; Junk et al., 2013). The flood pulse spreads from north to south due to the influence of the Amazon rain regime on the northern Paraguay River (Bergier et al., 2018; Hamilton et al., 2002; Oliveira et al., 2018) and reaches the south of the Pantanal months later during the dry season. The pulse shapes the extent of terrestrial and aquatic environments on the lowland, which determines the region's livestock and agricultural production areas (Abreu et al. 2010).

The UPRB is also among the regions of Brazil that have experienced the greatest landscape change in recent years, with anthropogenic use reaching 61% in the plateau and 13% in the lowland in 2016 (SOS Pantanal et al., 2017). Agriculture, livestock expansion and associated infrastructure development have been suggested as the main drivers of habitat degradation across this biome (Silva et al., 2011; Miranda et al., 2018), and the flood pulse is a key element for the dynamics of this system (Fig. 1) (Junk & Wantzen, 2004).

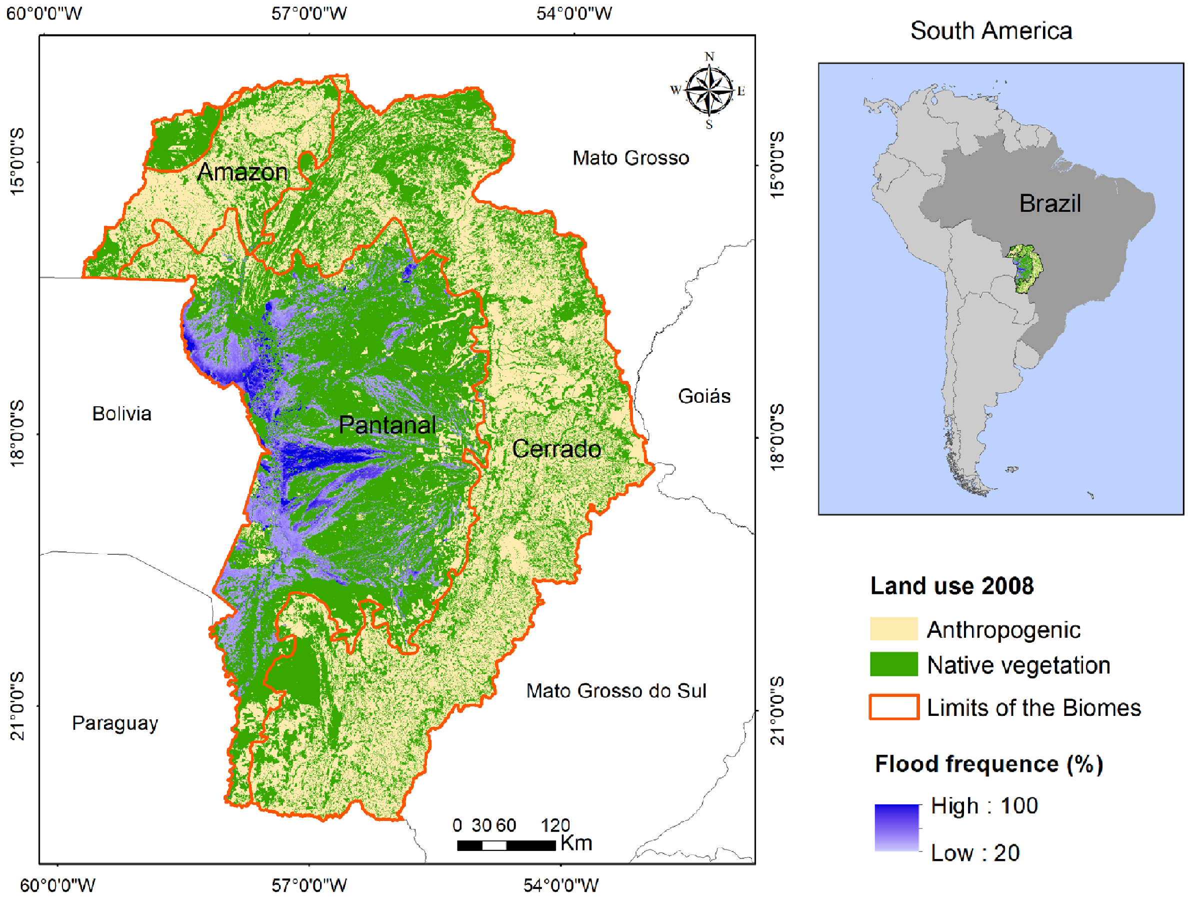

Fig. 1. Land use and flood pulse in the Upper Paraguay River Basin in 2008.

Data sources

To identify the drivers of native vegetation transformation in the studied area we first performed a literature review (Table A1). On the one hand, the expansion of agriculture and livestock were reported by several studies as the main drivers of native vegetation loss for the UPRB (Harris et al., 2005; Silva et al., 2011). In addition, owing to seasonal flooding in the Pantanal, many roads have been built using landfills to allow transit throughout the year (Tomas et al., 2009). It is known that the opening of roads, either officially or illegally, allows human expansion and (often illegal) occupation of land, and thus acts as a facilitator of native vegetation loss (Laurance et al., 2009). The expansion of cities into areas of native vegetation also acts as a vector of deforestation (Seto et al., 2012). On the other hand, native vegetation loss is expected to be lower in protected areas owing to restrictive land use measures (Bensusan, 2006).

For our model we used the rules of the Native Vegetation Protection Law (NVPL), which establishes that the width of "Área de Preservação Permanente" (APP; Permanent Protection Area) depends on the width of the river channel and slope areas (Brazil, # 12,651, of 2012) (see details in SI). To calculate Legal Reserve (LR) area, we followed the national legislation (NVPL), which establishes values of 20, 35, 50, and 80% depending on the biome in which the property is located and the size of the rural property (Soares-Filho et al., 2014, Brancalion et al., 2016). We also adopted the state legislation of Mato Grosso do Sul # 14,273 of 2015, which requires rural properties in the lowland Pantanal to have LRs of 40% in grassland formations and 50% in forest areas. We only used the Mato Grosso do Sul Decree because the Mato Grosso Decree does not mention legal reserve percentages for the Pantanal. Considering that the Pantanal has a greater proportion of grassland formations, we established a value of 40% for the entire area. Hence, the UPRB includes areas with LRs of 20, 35, 40, 50, and 80%, depending on where a rural property is located (Fig. S1). We used a shapefile with all properties located in the studied basin and registered in the "Cadastro Ambiental Rural" (CAR; Rural Environmental Registry, see details in Appendix A) until June 2018.

We obtained land use maps produced by SOS Pantanal et al. (2017), which is a non-governmental organization that has been regularly monitoring land use dynamics in UPRB. The following maps were available for our analysis: 2008-2010, 2010-2012, 2012-2014, and 2014-2016. These maps classify land as either 'natural' or under 'anthropogenic use' and were produced every two years. The thematic classification considers in its 'natural' class natural areas used as pastures, since cattle have been using native grasses as pasture for a century in the region. Anthropogenic areas are only classified as such when conversion from natural vegetation has been identified (e.g., when planted pastures are identified). The process of interpreting changes in the UPRB monitoring follows the IBGE legend standards (scale 1:100,000) (Veloso et al., 1991), considering the first level of vegetation grouping.

Apart from the land use maps, we collected a set of ten input variables for the model based on the potential drivers identified above (Table S1). All data were converted to the same resolution as the land use maps (600 m x 600 m) and projected onto the same coordinate system (WGS 1984 UTM Zone 21S). We then separated the variables into two categories: static and dynamic. Static variables were kept constant over time, either because they were assumed to not change over the time period analyzed (e.g., elevation, distance to rivers) or because we lacked data to update them (e.g., distance to roads, distance to cities, protected areas). Dynamic variables represent characteristics of the landscape that change over time, namely land use. We calculated the static variables only once, at the beginning of the modeling process, while the dynamic variables were recalculated at each time period (every two years). Finally, we used a dynamic variable to account for the neighborhood effect — the proportion of anthropogenic cells within the vicinity of the focal cell — which updates the odds of local native vegetation loss (Rosa et al., 2013, 2015).

Model

Our model is based on $P_{nvl,x,t}$ (Eq. 1), where P_{nvl} is the probability that a 'native vegetation' cell x is converted into 'anthropogenic use' within a defined time interval t (for full details see Rosa et al., 2013, 2015). The fact that $P_{nvl,x,t}$ is specific for a given time t illustrates how the model updates the suppression of local native vegetation over time. This probability was defined as a logistic function:

$$P_{nvl,x,t} = 1 / (1 + \exp -k_{x,t}) \qquad \text{Eq. 1}$$

such that as $k_{x,t}$ goes from infinity to infinity, $P_{nvl,x,t}$ goes from 0 to 1, following the methodology developed by Rosa et al. (2013). One can then develop linear models for $k_{x,t}$ as a function of the variables that affect x at time t, and explore the effect of different sets of variables using a model selection procedure (Fig. 2 for all modeling steps).

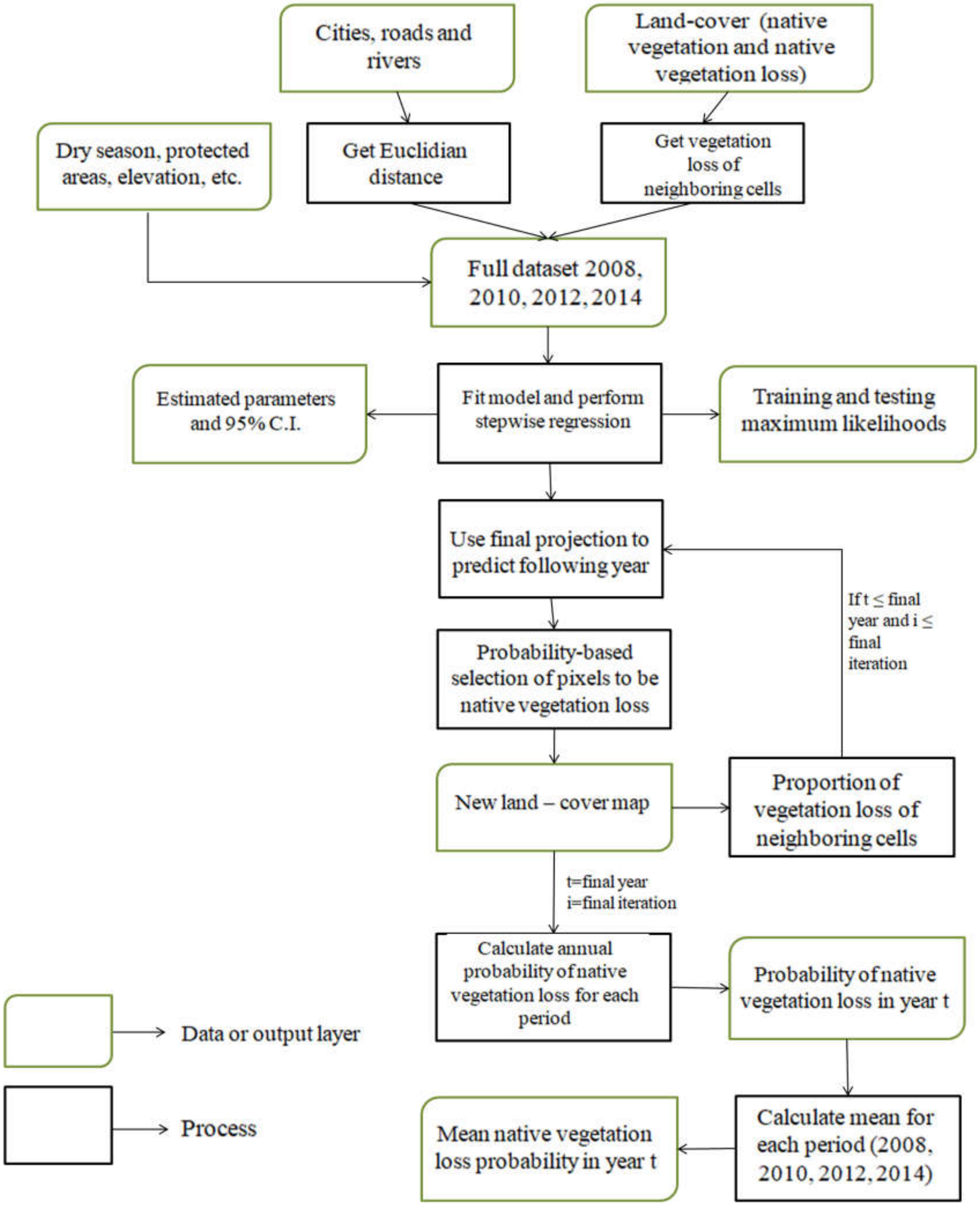

Fig. 2. Flowchart of modeling procedure (adapted from Rosa et al., 2013), illustrating the construction and running of the vegetation loss model. i is the model iteration, and t the time step.

The model uses Monte Carlo Markov Chains (MCMC) to obtain a posterior probability distribution for each parameter, from which the posterior mean and range of credibility can be extracted, given the model structure and data used for calibration. Binary maps of change are produced (1 – native vegetation, 0 – anthropogenic) for each time period, which are then integrated based on the 100 iterations of the model (sampling from the posterior distributions) to determine the overall probability of change (i.e., if a pixel is selected to be converted 100 times out of 100 iterations it has a 100% probability of conversion in time t). These steps were repeated for each of the four time periods as the model will project future conversion based on observed rates of change, and the periods (2008-2010, 2010-2012, 2012-2014, and 2014-2016) had different rates of change (see Fig. S2).

Once all models were calibrated, the best one (with the combination of variables that yield the highest test likelihood in each calibration time period) was used to project future probabilities of native vegetation loss until 2050 (using two-year time steps). The accumulated probability of conversion by 2050 was determined for each model individually (2008-2010, 2010-2012, 2012-2014, and 2014-2016 models) as well as based on an ensemble of all model outputs (i.e., integrating all model projections made for a particular year). To assess the goodness-of-fit of the models, we calculated the area under the receiver operating characteristic (or AUC) values for each period of each analyzed area (Table S2 of SI).

We generated projections for native vegetation loss patterns in UPRB for: (1) the basin as a whole; (2) the lowland; and (3) the plateau (allowing for the drivers to weigh in differently for the two regions). After calculating the average rate of vegetation loss for the four periods (2008-2010, 2010-2012, 2012-2014, and 2014-2016) for the two areas and the areas combined, we obtained the UPRB projection by executing the model for the whole area (UPRB) and for the lowlands and plateau (Low+Plat) separately, thus better reflecting sub-regional dynamics (Fig. S3).

Once we simulated future vegetation loss, we used MapBiomas Alert (a deforestation alert validation and refinement system in Brazil, http://alerta.mapbiomas.org/) to validate the areas with the highest land use conversion projected by our model.

Results

Drivers of native vegetation loss

Most of the variables had the expected impact on observed native vegetation loss but their importance varied both spatially (between lowland and plateau) and temporally (among the different calibration periods [2008, 2010, 2012, 2014, Table 1]). Commodity agriculture, represented in our models by agricultural potential, cattle ranching, area of permanent agriculture, and area of temporary agriculture, consistently led to higher probabilities of native vegetation loss over time, particularly in the plateau (Table 1). Conversely, protected areas were significant in reducing the probability of vegetation loss, with less native vegetation loss than in unprotected areas, except in 2010 (both in the plateau and lowland). Elevation was found to be a driver for vegetation loss for the lowland in 2010, 2012, and 2014, and for the plateau in 2010. Accessibility played a significant role in determining vegetation loss in the lowland, with the variable distance to roads leading to higher vegetation loss, but with no impact on the plateau. Finally, distance to cities and distance to rivers had a positive impact only in one time period (2010-2012), for the plateau and lowland, respectively (Table 1, see Model UPRB Table S3).

Table 1. Means for single variable models for the plateau and lowland separately.

	Plateau				Lowland			
Variables	2008	2010	2012	2014	2008	2010	2012	2014
Land Cover	1.109E+00	5.999E-07	9.564E-07	6.605E-07	3.635E+00	4.202E+00	2.426E+00	3.196E+00
Distance to roads	0	0	0	0	-1.000E-11	0	-1.100E-11	0
Distance to cities	0	1.000E-12	0	0	0	0	0	0
Dry season length	0	0	0	2.500E-07	-9.842E-07	-9.758E-07	-9.874E-07	-9.876E-07
Elevation	0	0	0	0	2.102E-09	0	5.910E-09	3.045E-09
Agricultural potential	1.825E-08	0	2.430E-10	7.000E-12	0	2.043E-07	0	0
Distance to rivers	0	0	0	0	0	3.000E-12	0	0
Cattle	6.574E-09	0	-1.470E-10	2.711E-09	1.429E-08	0	4.596E-09	0
Permanent agriculture	0	0	-2.930E-10	-6.450E-10	0	5.562E-09	0	0
Annual crop agriculture	-3.196E-09	0	3.150E-10	-2.179E-09	-6.319E-09	-5.377E-09	-1.582E-09	1.432E-09
Protected areas	-7.805E-07	0	4.222E-07	-4.968E-07	-1.679E+00	0	-1.576E+00	-1.787E+00

Projection of native vegetation loss

The cumulative rate of native vegetation loss projected by 2050 was 3% for the lowland and 10% for the plateau. These values represent an accumulated loss of 6,045 (± 363 95% C.I.) km² for the lowland and 7,960 (± 1,574 95% C.I.) km² for the plateau, for a total of 14,005 (± 1,937 95% C.I.) km^2 of native vegetation converted to anthropogenic use from 2018 to 2050 in the entire basin. The annual rate of vegetation loss was higher for the plateau than for the lowland for all periods (Fig. 3a), and these rates tended to decrease over the years. The rates of vegetation loss projected by the Lowland + Plateau models were lower than the UPRB model (Fig. 3b; see model UPRB in SI).

We mapped the probability of native vegetation loss in the UPRB by 2050 (Fig. 4) based on the cumulative annual probabilities of native vegetation loss generated for the plateau and lowland separately (the equivalent of the whole UPRB model presented in SI, Fig. S4). The chance of losing vegetation by 2050 reaches 74% in several areas of the plateau and in some bordering areas between the plateau and lowlands near areas already under high anthropogenic pressure (Fig. 4). An animation of the progression over time of the probability of loss of native vegetation from 2018 to 2050 under the UPRB can be found in https://tinyurl.com/y28xpl6b.

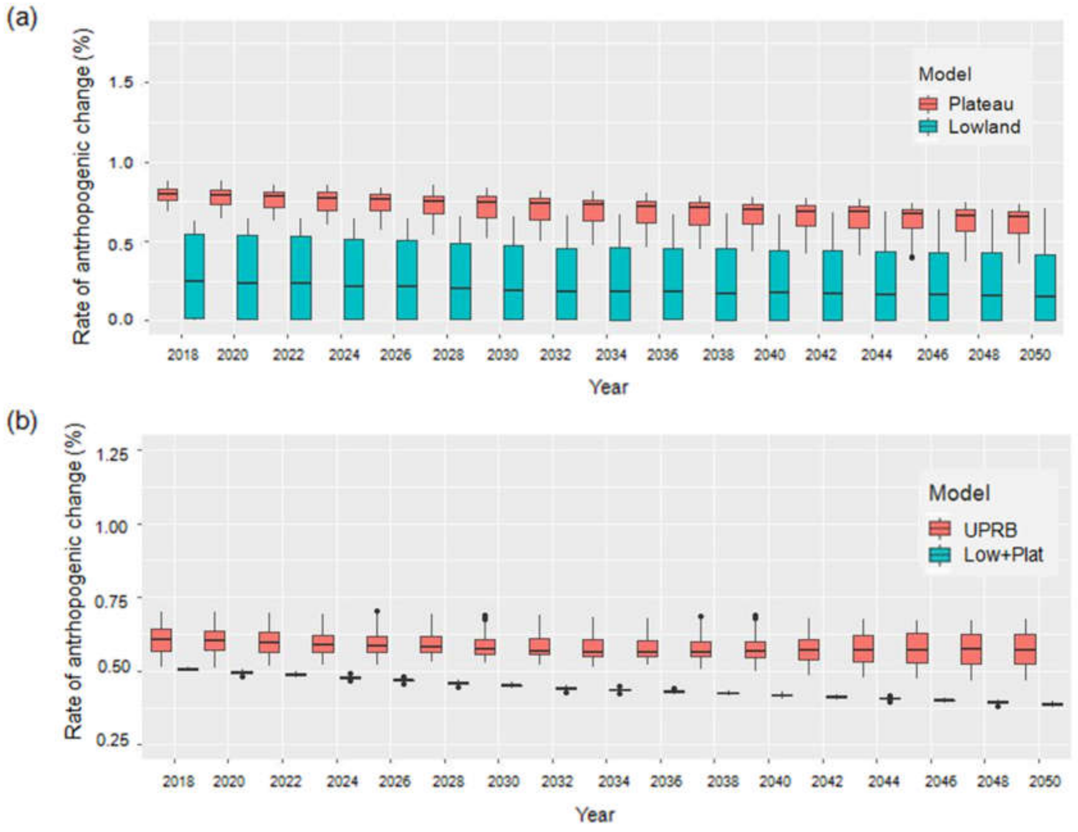

Fig. 3. Projections of annual rate of vegetation loss between 2018 and 2050 for the models of plateau and lowland separately (a), and for the model of the entire Upper Paraguay River Basin (UPRB) (b) where the model was executed for the whole area at the same time (UPRB) and for the lowlands and plateau (Low+Plat), where the model was run separately for the two regions, thus better reflecting sub-regional dynamics.

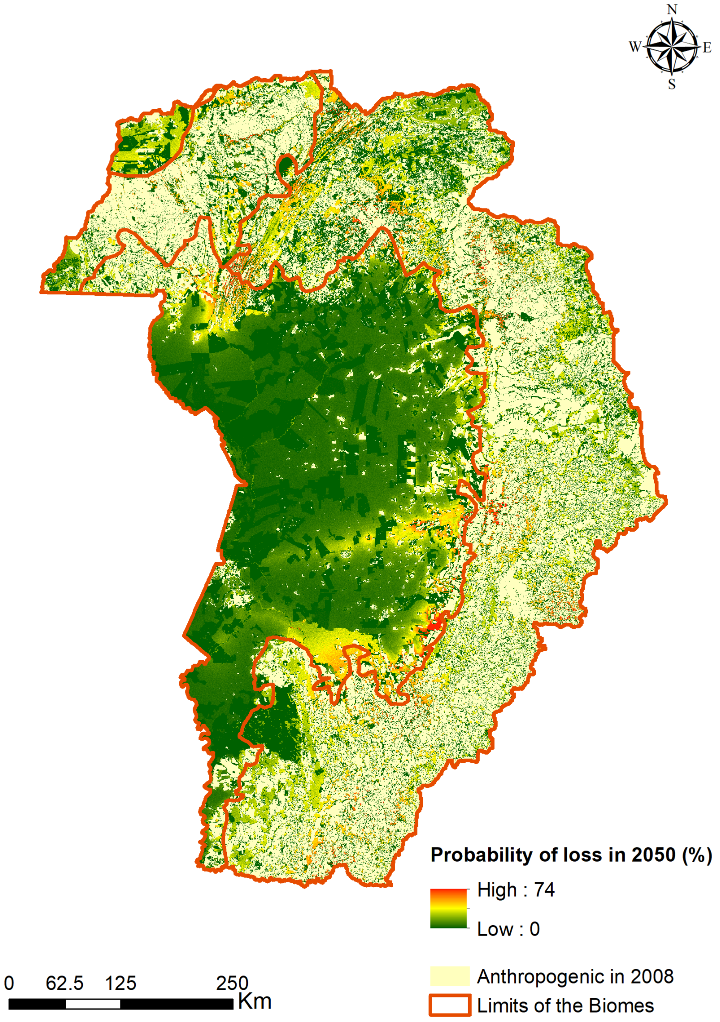

Fig. 4. Projections of accumulated native vegetation loss by 2050 for the mean values of the four periods (2008-2010, 2010-2012, 2012-2014 and 2014-2016) for models of lowlands + plateau.

Arc of native vegetation loss

Our simulations revealed that vegetation loss in the UPRB forms a geographic arc, much like what has been observed in the Amazon, i.e. the so-called 'Arc of Deforestation'. The arc starts on the plateau and continues through the border of the lowlands, i.e. the transition areas, where land use conversion has been occurring and is projected to continue at a faster rate (Fig. 5). Furthermore, we found a strong coincidence between our model's projections and the alerts from MapBiomas (Fig. 5).

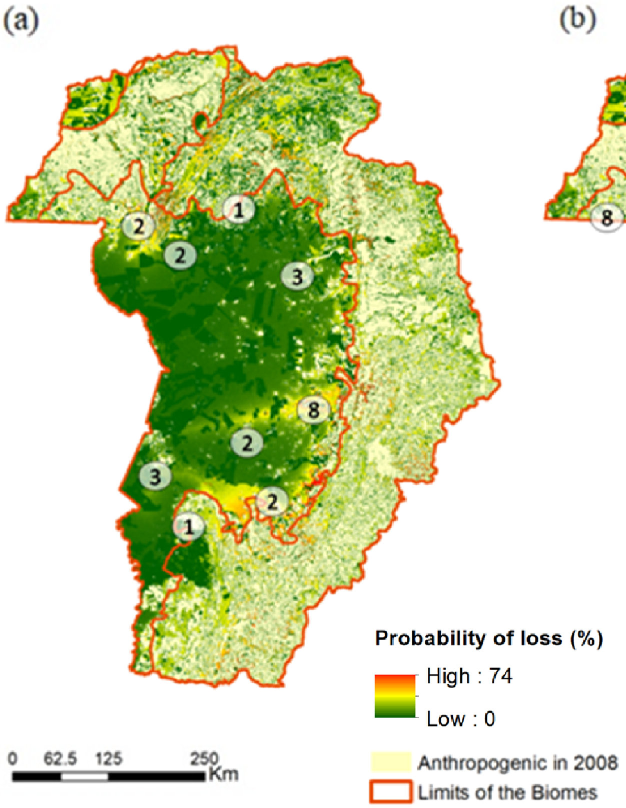

Fig. 5. Projection of vegetation loss in the UPRB based on the Lowland + Plateau model and validation by MapBiomas Alerta. Numbers (1 to 14) represent the number of areas experiencing vegetation loss as detected by MapBiomas Alerta for (a) July 2018 and (b) March 2019.

Discussion

Drivers of native vegetation loss

Building separate scenarios for the plateau and lowland allowed to estimate differential effects of LCLUC drivers within the two areas. Such differentiation is important from a policy perspective because it provides useful information for developing more targeted actions at the main relevant actors in each part of the UPRB. This may be important not only for the Pantanal, but for wetlands in general, since these environments usually depend on their surrounding areas.

Agriculture has been the world's greatest driver of landscape and biodiversity change (Foley et al., 2005, Godfray & Garnett, 2014, Struik & Kuyper, 2017), and it is expected to continue as such (Ferrier et al., 2016). Our results show that this is also true for UPRB, with variables associated with commodity agriculture strongly weighting on all models, and especially the plateau, which does not experience a flood pulse. The native vegetation of the plateau has been experiencing rapid depletion with replacement by mechanized agriculture since the 1970s, with a predominance of grain monoculture (soybean, maize, and cotton) and of sugarcane for the production of biofuels (Azevedo & Monteiro, 2003). The annual area of agriculture increased by 39% from 2001 to 2013, while sugar cane production increased by approximately 48% during the same period (Coutinho et al., 2016). Soybean cultivation in the region doubled between 2009 and 2016, rising from 3,000 to 6,000 km^2 (SOS Pantanal et al., 2017), which represents less than half of the projected loss of native vegetation until 2050 (14,005 km^2), evidencing the high-speed and recent increase of land conversion.

The change of natural areas to agriculture in the plateau has caused soil erosion and silting of rivers, altering their flow and hydrological regimes in the lowland, as has already been observed in the Upper Taquari Basin (Assine, 2005, Galdino et al., 2006). Furthermore, cattle density has increased more rapidly in the plateau than in the lowland (SOS Pantanal et al., 2017). Livestock farming was established in the UPRB in 1990, and contributes significantly to the region's economy. Today cattle breeding is an important tradition in the Pantanal, where it accounts for 65% of its economic activity (WWF, 2015). The states of Mato Grosso do Sul and Mato Grosso, where the UPRB is located, are the main cattle producers in the country, concentrating, respectively, 10% and 14% of the Brazilian herd (IBGE, 2018). Our model demonstrates that the trend is to continue - that is, the drivers of vegetation loss identified in the model are those that have historically shaped the landscape in the region, i.e. commodity agriculture, such as crop production and cattle ranching.

The role of roads in driving vegetation loss differed in the lowland and plateau. Much as in other tropical biomes (Laurance et al., 2009), we found that roads are important catalysts of native vegetation loss in the lowlands, and historically in the plateau where agriculture expansion was associated with rapid expansion of the road network (Castillo et al., 2011). In addition to a dense road network, the highest density of cities in UPRB is on the plateau. This location is also due to the flood dynamics in the lowlands where occupation is less frequent. Hence, our results showed that roads do not have an influence on vegetation loss in the plateau, probably due to these effects occurring in the past when the roads were built, well prior to the period of our analysis (from 2008). The UPRB Law (State Law # 8,830, of 2008) of the state of Mato Grosso allows the construction of roads to access rural properties in permanent conservation areas (floodplains, corbels, river meanders, marginal bays, lagoons, mountain ranges, natural marginal dikes, bush beds, and murunduns), as long as they do not block water flow. Our analyses only took into account official roads; in the case of the lowland, which holds a large number of unofficial roads, this variable should have a larger effect (e.g., Barber et al., 2014). Furthermore, our model did not consider new roads (e.g. trans-ocean construction), which may open new frontiers for agriculture development and hence native vegetation loss. Future road construction will lead to increased transportation and consequently more land use change.

However, projecting when and where these roads will actually be built is highly uncertain, therefore, we adopted a conservative approach of retaining the road network as it is presently defined.

The result indicating that the distance of rivers only explained the loss of vegetation in the lowland and only in the period 2010-2012, it is possibly due to the extreme drought that occurred in 2012 in the Pantanal (see http://glo.bo/QXRrS3), suggesting that in periods of severe drought, land use change tends to occur closer to rivers. Our results showed the importance of considering wetland dynamics, such as with the Pantanal, that are governed by a flood pulse. Flood pulses add complexity to models since they are related to the presence of other drivers of native vegetation loss, such as the presence of roads, cities and permanent agriculture. Although we did not include flood pulse in the model of the present study, it is evident that vegetation loss was not predicted for areas with 20% or more flood frequency, owing to the biophysical constraints it presents (Figs. 1 and 4).

Besides the conversion of land for specific uses, including livestock and agriculture, environmental legislation also has an impact on conversion rates. We highlight an increase in land conversion in the lowland during 2008-2010, whereas it increased in the plateau between 2014-2016 (Fig. S2). The Cerrado experienced a decrease in conversion rates from 2005 to 2010, and then remained constant until 2015 when it began to rise and continued to do so in subsequent years (Rochedo et al., 2018). This trend may have been partially a result of the soy expansion, a major driver of recent clearing in the Cerrado (Rausch et al., 2019; Sorretoni et al., 2019). Moreover the increase in the land-use conversion for agriculture may be associated to the Native Vegetation Protection Law (NVPL) of Brazil, popularly known as the ‘New Forest Code’ in 2009 (Sorretoni et al., 2018). From that year onwards (when the bill that intended to change the Forest Code of 1965 was presented in Congress), the bill opened up possibilities for decreasing several conservation and restoration requirements in the Cerrado, while in the Pantanal there was a time lag after the approval of a new law (NPVL) in 2012 allowing for new legal land use conversions (Garcia et al., 2013; Soares-Filho et al., 2014; Brancalion et al., 2016). Hence, improved legal enforcement will do little to eliminate clearing for agriculture in the Cerrado (see Rausch et al., 2019) and the Pantanal because most of it takes place within legal limits. Compared to the previous law (from 1965) this new law (NPVL) allows certain vegetation to be legally converted.

Projection of native vegetation loss

By 2016, the percentage of the lowland in UPRB under anthropogenic use was 13%, while on the plateau it was 61% (SOS Pantanal et al., 2017). Our projections reveal that these areas can reach, respectively, 17% (± 1.4 95% C.I.) and 65% (± 1.2 95% C.I.) by 2050. These values may be conservative because they do not consider a strong increase in commodity agriculture, neither do they include potential future infrastructure development. Furthermore, the current Government recently revoked (Decree # 10,084/2019) a legal impediment of agro-ecological zoning (Decree # 6,961/2009) that used to prevent the advance of sugarcane plantations in Pantanal, the UPRB, and the Amazon. Hence, releasing the ban on sugarcane farming in these ecologically vulnerable regions may lead to further land use conversion beyond those projected by our model.

In addition, the low conversion rate of native vegetation projected for the lowlands considers the entire area of the region (151,119 km²), and not only the areas that can be converted, which are areas that do not have a flood pulse. As a result, the projected loss of more than 6,000 km² for the lowlands is concentrated in a small area in the transition with the plateau, which can result in the loss of important ecosystem services. It is worth emphasizing that these values are considering full compliance with the NPVL. This loss of vegetation, mainly on the plateau, is likely to have environmental impacts (river sedimentation, change in the flood regime, habitat loss) in the lowlands owing to sediment transport from the plateau (Abdon et al., 2005). Loss of vegetation can increase sediment flow to 191% and water discharge to 82% in the lowlands, which can lead to significant changes in flood dynamics and ecosystem functions and services (Bergier, 2013). Therefore, an expected increase in conversion of native vegetation into other uses can cause important changes in the intensity and duration of floods. This may have long-term impacts on the distribution and survival of species in the Pantanal (Junk et al., 2006), as is the case with migratory species of fish and birds (Resende, 2003, Nunes & Tomas, 2004). In addition, 62 plant species that are listed among three threat categories (IUCN) (Loyola et al., 2014) occur in the basin (12 in the Pantanal), with the effect of changing land use on them remaining unknown. Hence, there is an urgent need not only to understand what drives LCLU in this wetland, but also to map existing priority areas for conservation and restoration of the Pantanal and its surroundings. The present study aims to support such efforts by highlighting areas under greater threat of conversion.

Arc of native vegetation loss

Our simulations revealed a geographic pattern in land use change at the borders between the Cerrado, Pantanal, and Amazonia biomes in the form of an arc. Instead of an "Arc of Deforestation", as in the Amazon, this pattern is better referred to as an arc of vegetation loss, since much of the area is actually represented by non-forest systems including grassland and savanna. Identifying this arc offers new perspectives for management and the urgent development of policies for the conservation of this wetland. Mapbiomas Alerta revealed that, as of October 2018, the UPRB had 24 vegetation loss alert areas, and that the number increased rapidly to 85 areas in 2019, with most being in the area of transition between the Pantanal and Cerrado, in the area of the arc (Fig. 5). The arc is located on areas that do not, or infrequently, flood, demonstrating a clear pattern of agricultural expansion into non-flooding areas. It is expected, therefore, that land conversion would extend through borders into wetlands until reaching areas that flood, since flood dynamics will always be a significant challenge for the most common crops or pastures. The loss in the arc of vegetation is likely to be accompanied by a higher frequency of fires in the future. Fire management (such as prescribed fires and creation of firebreaks) should be one of the priorities. However, it is noteworthy that fire management in wetlands is extremely complex, as it involves relationships between flood pulse, biomass, and land uses (De Oliveira et al., 2014; de Sá Arruda et al., 2016).

Our results corroborate other studies that highlight an urgent need for clear conservation policies for the Pantanal and its surroundings involving different sectors and based on scientific evidence (Alho & Sabino, 2011, Roque et al., 2016). Such efforts should include the creation of new protected areas, particularly in areas under greater pressure, and the maintenance of the current conservation unit system, which seems to have been efficient in preventing the loss of native vegetation in the UPRB (Table 1). Considering that 85% of the Pantanal is occupied by private lands, strategies to preserve this important biome should focus on strategies for private properties, such as payments for ecosystem services, tax incentives and for sustainable value chains.

Simulations, such as those performed here, can help society develop social, ecological and environmental strategies towards sustainability. By identifying areas of rapid land use change, our study allows stakeholders and decision-makers to make decisions about where actions are more relevant to transform the future. For example, we believe that for the arc of vegetation loss, beyond the general actions already suggested for the entire Pantanal and surrounding area (Lourival et al., 2009, Roque et al., 2016, Tomas et al., 2019, Schulz et al. 2019), innovations that consider the rapid rate of change and opportunities expected for the zone in the coming years are needed. Among these innovations, we suggest that approaching the arc as a Sustainability Transition Zone would open new avenues for management and governance (see Loorbach et al., 2017). Under this perspective, a wider range of governance instruments can be employed, such as incubation of spaces for disruptive initiatives of economic chains based on ecological services, facilitated by government interventions. Such instruments can change the current trend in the arc from being just one more case of rapid land use change focused on the production of commodities in the tropics, towards a new history of conciliation between food production and the conservation of biodiversity and ecological services.

References

Abessa, D., Famá, A., & Buruaem, L. (2019). The systematic dismantling of Brazilian environmental laws risks losses on all fronts. Nature Ecology & Evolution, 3, 510–511. http://dx.doi.org/10.1038/s41559-019-0855-9

Abdon, M. M., Souza, M. P., & Silva, J. S. V. (2005). Identificação de impactos ambientais no meio físico subsidiada por banco de dados georreferenciados. In: Anais do XII Simpósio Brasleiro de Sensoriamento Remoto. Goiânia, Brasil. (pp. 2793-2798), INPE.

Abreu, U. G. P., McManus, C., Santos, S. A. (2010). Cattle ranching, conservation and transhumance in the Brazilian Pantanal. Pastoralism, 1, 99–114.

Alho, C. R. J. & Sabino, J. (2011). A conservation agenda for the Pantanal's biodiversity. Brazilian Journal of Biology, 71(1), 327-335. http://dx.doi.org/10.1590/S1519-69842011000200012

Assine, M. L. (2005). River avulsions on the Taquari megafan, Pantanal wetland, Brazil. Geomorphology, 70, 357–371. http://dx.doi.org/10.1016/j.geomorph.2005.02.013

Azevedo, A. A., & Monteiro, J. L. G. (2003). Análise dos impactos ambientais da atividade agropecuária no Cerrado e suas inter-relações com os recursos hídricos na região do Pantanal. In: Jaccoud, D., Stephan, P., Sá, R. L. de, Richardson S., Fecuri, J. (Eds.), A avaliação de sustentabilidade do crescimento do cultivo da soja para exportação no Brasil. Brasília: WWF.

Bai, X., van der Leeuw, S., & O'Brien, K. (2015). Plausible and desirable futures in the Anthropocene: A new research agenda. Global Environmental Change, 39, 351–362. https://doi.org/10.1016/j.gloenvcha.2015.09.017

Barber, C. P., Cochrane, M. A., Souza Jr, C. M., & Laurance, W. F. (2014). Roads, deforestation, and the mitigating effect of protected areas in the Amazon. Biological Conservation, 177, 203-209. https://doi.org/10.1016/j.biocon.2014.07.004

Bensusan, N. (2006). Conservação da biodiversidade: em áreas protegidas. Rio de Janeiro: FGV.

Bergier, I. (2013). Effects of highland land-use over lowlands of the Brazilian Pantanal. Science of the Total Environment, 463, 1060–1066. https://doi.org/10.1016/j.scitotenv.2013.06.036

Bergier, I., Assine, M. L., McGlue, M. M., Alho, C. J. R., Silva, A., Guerreiro, R. L., & Carvalho, J. C. (2018). Amazon rainforest modulation of water security in the Pantanal wetland. Science of the Total Environment, 619, 1116–1125. https://doi.org/10.1016/j.scitotenv.2017.11.163

Bradley, A. V., Rosa, I. M. D., Brandão Jr, A., Crema, S., Dobler, C., Moulds, S., Ahmed, S. E., Carneiro, T., Smith, M. J. & Ewers, R. M. (2017). An ensemble of spatially explicit land-cover model projections: prospects and challenges to retrospectively evaluate deforestation policy, Model. Earth Systems and Environment, 3, 1215–1228. https://doi.org/10.1007/s40808-017-0376-y

Brancalion, P. H. S., Garcia, L. C., Loyola, R., Rodrigues, R. R., Pillar, V. D. & Lewinsohn, T. M. (2016). A critical analysis of the Native Vegetation Protection Law of Brazil (2012): updates and ongoing initiatives. Natureza e Conservação, 14, 1-15. https://doi.org/10.1016/j.ncon.2016.03.003

Castillo, R., Vencovsky, V. P., & Braga, V. (2011). Logistics and intensive agriculture in the Cerrado: the new Brazilian railroad system. Terrae, 8(1-2): 19-25.

Costanza, R., d’ Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., … van den Belt, M. (1997). The value of the world’s ecosystem services and natural capital. Nature, 387(6630), 253–260. https://doi.org/10.1016/S0921-8009(98)00020-2

Coutinho, A. C., Bishop, C., Esquerdo, J. C. D. M., Kastens, J. H., & Brown, J. C. (2016). Dinâmica da agricultura na Bacia do Alto Paraguai. In: Anais 6º Simpósio de Geotecnologias no Pantanal, Cuiabá, MT. (pp. 623) Embrapa Informática Agropecuária/INPE.

Davidson, N. C., Van Dam, A. A., Finlayson, C.M., McInnes, R.J. (2019). Worth of wetlands: Revised global monetary values of coastal and inland wetland ecosystem services. Marine and Freshwater Research. https://doi.org/10.1071/MF18391

de Oliveira, M. T., Damasceno-Junior, G. A., Pott, A., Paranhos Filho, A. C., Suarez, Y. R. Parolin, P. (2014). Regeneration of riparian forests of the Brazilian Pantanal under flood and fire influence. Forest Ecology and Management, 331, 256-263. https://doi.org/10.1016/j.foreco.2014.08.011

de Sa Arruda, W., Oldeland, J., Paranhos Filho, A. C., Pott, A., Cunha, N. L., Ishii, I. H. Damasceno-Junior, G. A. (2016). Inundation and fire shape the structure of riparian forests in the Pantanal, Brazil. PloS one, 11(6), e0156825. https://doi.org/10.1371/journal.pone.0156825

Ferrier, S., Ninan, K. N., Leadley, P., Alkemade, R., Acosta, L. A., Akçakaya, H. R., Brotons, L., Cheung, W. W. L., Christensen, V., Harhash, K. A., Kabubo-Mariara, J., Lundquist, C., Obersteiner, M., Pereira, H. M., Peterson, G., Pichs-Madruga, R., Ravindranath, N., Rondinini, C. & Wintle, B. A. (2016). The methodological assessment report on scenarios and models of biodiversity and ecosystem services (IPBES).

Foley, J. A., Defries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., … Snyder, P. K. (2005). Global consequences of land use. Science, 309(5734), 570–574. http://www.jstor.org/stable/3842335

FAO - Food and Agriculture Organization of the United Nations (2016). Global forest resources assessment 2015. Rome: Forestry Dept.

Galdino, S., Vieira, L. M. & Pelegrin, L. A. (2006). Impactos ambientais e socioeconômicos na Bacia do Rio Taquari – Pantanal. Corumbá: Embrapa Pantanal.

Garcia, L. C., Santos, J. S., Matsumoto, M., Silva, T. S. F., Padovezi, A., Sparovek, G., & Hobbs, R.J. (2013). Restoration Challenges and Opportunities for Increasing Landscape Connectivity under the New Brazilian Forest Act. Natureza & Conservação, 11, 181-185. http://dx.doi.org/10.4322/natcon.2013.028

Godfray, H. C. J. & Garnett. T. (2014). Food security and sustainable intensification. Philosophical Transactions of the Royal Society B, 369, 20120273. https://doi.org/10.1098/rstb.2012.027

Hamilton, S.K. (2002). Hydrological controls of ecological structure and function in the Pantanal wetland (Brazil). The Ecohydrology of South American Rivers and Wetlands. 6. International Association of Hydrological Sciences, pp. 133–158 Special Publication

Harris, M., Arcangelo, C., Pinto, E. C. T., Camargo, G., Neto, M. B. R. & Silva, S. M. (2005). Estimativa de perda da área natural da Bacia do alto Paraguai e Pantanal Brasileiro. Campo Grande: Conservation International.

Hartig, J.H., Bennion, D., (2017). Historical loss and current rehabilitation of shoreline habitat along an urban-industrial river-Detroit River, Michigan, USA. Sustainainability 9, 828

IBGE - Instituto Brasileiro de Geografia e Estatística (2018). Estatística da produção pecuária. Retrieved from: https://biblioteca.ibge.gov.br/visualizacao/periodicos/2380/epp_2018_2tri.pdf

INPE - Instituto Nacional de Pesquisas Espaciais (2016). Projeto PRODES, Monitoramento da floresta Amazônica Brasileira por satélite.

Junk, W. J. & Wantzen, K. M. (2004). The Flood Pulse Concept: New Aspects, Approaches, and Applications – an Update. In: Welcomme, R. L. & Petr, T. (eds.), Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries, Volume 2, Food and Agriculture Organization & Mekong River Commission, RAP Publication 2004/16, FAO Regional Office for Asia and the Pacific, Bangkok., pp. 117–149.

Junk, W. J., Cunha, C. N., Wantzen, K. M., Petermans, P., Strussmann, C., Marques, MI. & Adis, J. (2006). Biodiversity and its conservation in the Pantanal of Mato Grosso, Brazil. Aquatic Sciences, 68, 278-309. https://doi.org/10.1007/s00027-006-0851-4

Junk, W. J., da Silva, C. J., Nunes da Cunha, C. (Eds.) (2011). The Pantanal: Ecology, biodiversity and sustainable management of a large neotropical seasonal wetland. Sofia [et al.]: Pensoft Publishers.

Junk, W. J., Piedade, M. T. F., Lourival, R., et al. (2013). Brazilian wetlands: their definition, delineation, and classification for research, sustainable management, and protection. Aquatic Conservation: Marine Freshwater Ecosystems, 24, 5–22. http://dx.doi.org/10. 1002/aqc.2386

Kehoe, L., Rei, T., Virah-Sawmy, M., Balmford, A., & Kuemmerie T. (2019). Make EU trade with Brazil sustainable. Science, 364 (6438) 341. https://doi.org/10.1126/science.aaw8276

Lathuillière, M. J., Coe, M. T., & Johnson, M. S. (2016). A review of green- and blue-water resources and their trade-offs for future agricultural production in the amazon basin: What could irrigated agriculture mean for Amazonia? Hydrology and Earth System Sciences, 20(6), 2179–2194. https://doi.org/10.5194/hess-20-2179-2016

Laurance, W. F., Cochrane, M. A., Bergen, S., Fearnside, P. M., Delamonica P., Barber, C., DÁngelo, S. & Fernandes, T. (2001). The future of the Brazilian Amazon. Science, 291, 438-439. https://doi.org/10.1126/science.291.5503.438

Laurance, W. F., Goosem, M. & Laurance S. G. (2009). Impacts of roads and linear clearings on tropical forests. Trends in Ecology & Evolution, 24, 659-669. https://doi.org/10.1016/j.tree.2009.06.009

Loorbach, D., Frantzeskaki, N. & Avelino, F. (2017). Sustainability transitions research: transforming science and practice for societal change. Annual Review of Environment and Resources, 42(1), 599-626. https://doi.org/10.1146/annurev-environ-102014-021340

Lorran, T. (2019). No Senado, Flávio Bolsonaro retira PL que acabava com reserva legal. Metrópoles, Meio Ambiente. Retrieved from: https://www.metropoles.com/brasil/meio-ambiente-brasil/no-senado-flavio-bolsonaro-retira-pl-que-acabava-com-reserva-legal

Lourival, R., McCalunn, H., Grigg, G., Arcangelo, C., Machado, R., & Possingham, H. (2009). A systematic evaluation of the conservation plans for the Pantanal wetland in Brazil. Wetlands, 29(4), 1189-2001. https://doi.org/10.1672/08-118.1

Loyola, R., Machado, N., Nova, D. V., Martins, E. & Martinelli, G. (2014). Áreas prioritárias para conservação e uso sustentável da flora brasileira ameaçada de extinção. Rio de Janeiro: Instituto de Pesquisas Jardim Botânico.

Miranda, C. S., Gamarra, R. M., Mioto, C. L., Silva, N. M., Conceição Filho, A. P., Pott, A. (2018). Analysis of the landscape complexity and heterogeneity of the Pantanal wetland. Brazilian Journal of Biology, 78, 318-327. http://dx.doi.org/10.1590/1519-6984.08816

Nogueira, F., Silva, R. L., Silva, A. J., Souza, M. D., Bachega, I. (2002). Seasonal and diel limnological differences in a tropical floodplain lake (Pantanal of Mato Grosso, Brazil). Acta Limnologica Brasiliensia, 14(3), 17–25

Nunes, A. P., Tomas, W. M. (2004). Aves migratórias ocorrentes no Pantanal: caracterização e conservação. Corumbá: Embrapa Pantanal.

Oliveira, E.C., Pla-Pueyo, S., Hackney, C.R. (2018). Natural and anthropogenic influences on the Nhecolândia wetlands, SE Pantanal, Brazil. Geological Society, London, Special Publications, 488.

Rausch, L. L., Gibbs, H. K., Schelly, I., Brandão, A., Morton, D. C., Filho, A. C., Strassburg, B., Walker, N., Noojipady, P., Barreto, P., Meyer, D. (2019). Soy expansion in Brazil's Cerrado. Conservation Letters. doi:10.1111/conl.12671

Reis, V., Hermoso, V., Hamilton, S.K., Ward, D., Fluet-Chouinard, E., Lehner, B., Linke, S., (2017). A global assessment of inland wetland conservation status. Bioscience 67, 523–533.

Resende, E. K. (2003). Peixes como recurso sustentável do Pantanal. Corumbá: Embrapa Pantanal;

Rochedo, P. R. R., Soares-Filho, B., Schaeffer, R., Viola, E., Szklo, A., Lucena, A. F. P., … Rathmann, R. (2018). The threat of political bargaining to climate mitigation in Brazil. Nature Climate Change, 8(8), 695–698. https://doi.org/10.1038/s41558-018-0213-y

Roque, F. O., Ochoa-Quintero, J., Ribeiro, D. B., Sugai, L. S. M., Costa-Pereira, R., Lourival, R., & Bino G. (2016). Upland habitat loss as a threat to Pantanal wetlands. Conservation Biology, 30(5) 1131-1134. https://doi.org/10.1111/cobi.12713

Rosa, I. M. D., Purves, D., Souza, C. & Ewers, R. M. (2013). Predictive modelling of contagious deforestation in the brazilian Amazon, PloS ONE, 8, e7723. https://doi.org/10.1371/journal.pone.0077231

Rosa, I. M. D., Purves, D., Carreiras, J. M. B., Ewers, R. M. (2015). Modelling land cover change in the Brazilian Amazon: temporal changes in drivers and calibration. Regional environmental change, 15 (1) 123-137. https://doi.org/10.1007/s10113-014-0614-z

Rosa, I. M. D. et al. (2017). Multiscale scenarios for nature futures. Nature Ecology & Evolution, 10, 1416–1419. https://doi.org/10.1038/s41559-017-0273-9

Schulz, C., Whitney, B. S., Rossetto, O. C., Neves, D. M., Crabb, L., de Oliveira, E. C., Lima, P. L. T., Afzal, M., Laing, A., de Souza Fernandes, L. C. da Silva, C. A., (2019). Physical, ecological and human dimensions of environmental change in Brazil's Pantanal wetland: Synthesis and research agenda. Science of the total environment, 687, 1011-1027. https://doi.org/10.1016/j.scitotenv.2019.06.023

Seto, K. C., Güneralp, B. & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Sciences, 109, 16083-16088. https://doi.org/10.1073/pnas.1211658109

Silva, J. S. V., Abdon, M. M., Silva, S. M. A. & Moraes, J. A. (2011). Evolution of deforestation in the Brazilian Pantanal and surroundings in the timeframe 1976-2008. Geografia, 36, 35-55.

Soares-Filho, B. et al. (2014). Cracking Brazil's forest code. Science, 344, 363–364. https://doi.org/10.1126/science.1246663

Soares-Filho, B. S., Nepstad, D. C., Curran, L. M., Cerqueira, G. C., Garcia, R. A., Ramos, C. A., Voll, E., McDonald, A., Lefebvre, P., Schlensinger, P. (2006). Modelling conservation in the Amazon basin. Nature, 440, 520. https://doi.org/10.1038/nature04389

Sorretoni, A. C., Mosnier, A., Carvalho, A. X. Y., Camara, G., Obersteiner, M., Andrade, P. R., Souza, R. C., Brock, R., Pirker, J., Kraxner, F., Havlik, P., Kapos, V., Ermgassen, E. Z., Valin, H., Ramos, Fernando M. (2018). Future environmental and agricultural impacts of Brazil's Forest Code. Environmental Research Letters, 13, 074021. https://orcid.org/0000-0003-3113-096X

Soterroni, A. C., Ramos, F. M., Mosnier, A ; Fargione, J., Andrade, P. R., Baumgarten, L., Pirker, J., Obersteiner, M., Kraxner, F., Camara, G., Carvalho, A. X. Y., Polasky, S. (2019). Expanding the Soy Moratorium to Brazil's Cerrado. Science Advances, 5, eaav7336. 10.1126/sciadv.aav7336

Spera, S. A., Galford, G. L., Coe, M. T., Macedo, M. N., & Mustard, J. F. (2016). Land-use change affects water recycling in Brazil's last agricultural frontier. Global change biology, 22(10), 3405-3413. https://doi.org/10.1111/gcb.13298

SOS-Pantanal, WWF-Brasil, Conservation-International, ECOA, Fundación-AVINA. (2017). Monitoramento das alterações da cobertura vegetal e uso do solo na Bacia do Alto Paraguai Porção Brasileira-Período de análise: 2016 a 2017. Corumbá: Embrapa Pantanal.

Struik, P. C. & Kuyper, T. W. (2017). Sustainable intensification in agriculture: the richer shade of green. A review. Agronomy for Sustainable Development, 37-39. https://doi.org/10.1007/s13593-017-0445-7

Tomas, W. M., Mourão, G. M., Campos, Z. M. S., Salis, S. M. & Santos, S. A. (2009). Intervenções humanas na paisagem e nos habitats do Pantanal. Corumbá: Embrapa Pantanal.

Tomas, W. M. et al. (2019). Sustainability agenda for the Pantanal wetland: perspectives for a collaborative interface among science, policy, and decision-making. Tropical Conservation Science.

Veloso, H. P., Rangel-Filho, A. L. R. & Lima, J. C. A. (1991). Classificação da vegetação brasileira, adaptada a um sistema universal. Rio de Janeiro: IBGE, Departamento de Recursos Naturais e Estudos Ambientais.

Zedler, J.B. & Kercher, S. (2005). Wetland Resources: Status, Trends, Ecosystem Services, and Restorability. Annual Review of Environmental Resources, 30, 39-74. http://dx.doi.org/10.1146/annurev.energy.30.050504.144248

Zeidan, R. (2019). The deforestation bill as a threat to biodiversity. Nature Ecology & Evolution.

WWF - World Wide Found to Nature (2015). 10 years of sustainable beef production in the Pantanal (2004-2014) - The story of a project that brings together the beef value chain and WWF-Brasil in an effort to promote the sustainable development of the biome. Brasília: WWF-Brasil.

Supporting Information for Chapter 1

Native Vegetation Protection Law

The Native Vegetation Protection Law (NVPL), which establishes that the width of "Área de Preservação Permanente" (APP; Permanent Protection Area) depends on the width of the river channel: (a) 30 m for water courses less than 10 m wide; (b) 50 m for water courses ranging from 10 to 50 m wide; (c) 100 m for water courses ranging from 50 to 200 m wide; (d) 200 m for water courses ranging from 200 to 600 m wide; and (e) 500 m for water courses greater than 600 m wide (Brazil, # 12,651, of 2012). However, we acknowledge that these minimum dimensions are not for rural properties that did not comply with the former law (Forest Code of 1964), for which NPVL defined that the width APP of riparian vegetation to be restored depends on the size of the rural property and not only the river width (see Fig. 6 of Brancalion et al., 2016). Hence, our model considered all vegetation as being on land of an owner who complied with the former law. We also considered APP in slope areas according to NVPL: on slopes greater than 45°, equivalent to 100% in the line of greatest decline.

According to the Decree #7,830 of 2012, the NVPL created the Environmental Rural Registry ("Cadastro Ambiental Rural," CAR, in Portuguese). The CAR is a mandatory self-declaratory electronic registration system, which consists of collecting georeferenced information of all rural properties. Landowners are required to delineate Areas of Permanent Protection (APP), Legal Reserve (LR), remnants of native vegetation, consolidated rural areas, areas of social interest and public interest, in order to draw a full digital map of their properties from which the values of the areas for environmental diagnosis are calculated. To ensure that the property fits to the environmental regularization in the Environmental Compliance Program ("Programa de Regularização Ambiental", PRA, in Portuguese), after registration, the state environmental agency (IMASUL) verifies the mapping. If the property has environmental liabilities, the landowner will need to commit to recover the damage caused before the property or by buying an Environmental Reserve Quota ("Cota de Reserva Ambiental," CRA, in Portuguese) in the case of environmental liabilities of LR (CRA is only for legal compliance of RL) or by restoring the LR. In case of environmental liabilities of APP, the owner has the obligation to restore the APP.

Results for UPRB Model

The important variables in all the periods for the UPRB model were dry season duration, elevation, cattle herds, and annual crop agriculture (Table A3). Permanent agriculture and protected areas were significant in three of the four periods. The agricultural potential was significant in just two periods and distance from the roads in only one period (2008-2010). The distance from the rivers and cities was not significant for the model (Table A3).

Our projection predicts that from 2016 to 2050, 14% of the native vegetation of the lowland and 23% of the plateau will be converted into anthropogenic areas. These rates result in 23% of anthropogenic use by 2050 for the lowlands and 75% for the plateau. These values are much larger than those designed by the Lowlands + Plateau models. We mapped the probability of loss of native vegetation by 2050 (Fig. A4), based on the cumulative probabilities of native vegetation. The probability of maximum loss of vegetation reaching 86%, with the highest rates located in the plateau. We constructed a video with the evolution of vegetation loss between the years 2018 and 2050 for UPRB Model (https://tinyurl.com/y5l844kb).

Table S1. Details of the input data used to calibrate the model for transition period 2008-2010, 2010-2012, 2012-2014, and 2014-2016 (data name, description, source, and reference year).

Name	Description	Source	Year
Land Cover	Natural (1), Anthropogenic (0)	SOS Pantanal[1]	08-10-12-14-16
Distance to roads	Euclidean distance to nearest road (m)	IBGE[2]	-
Distance to cities	Euclidean distance to nearest city (m)	IBGE[2]	-
Dry season length	Number of months with precipitation <100mm	WMO[3]	-
Elevation	Altitude (m)	SRTM[4]	-
Agricultural potential	Quality of soil/climate for agriculture	IBGE[2]	-
Distance to Rivers	Euclidean distance to nearest river (m)	IBGE[2]	-
Cattle	Change in cattle heads	IBGE[2]	08-10, 10-12, 12-14, 14-16
Permanent Agriculture	Change in permanent agriculture area	IBGE[2]	
Annual Crop Agriculture	Change in temporary agriculture area	IBGE[2]	
Protected areas	Protected áreas (1), unprotected (0)	IBGE[2]	-

[1] SOS Pantanal – SOS Pantanal (https://www.sospantanal.org.br/arquivos/projetos/mapeamento-da-cobertura-vegetal-da-bacia-do-alto-paraguai-bap).

[2] IBGE – Instituto Brasileiro de Geografia e Estatística (http://www.ibge.gov.br/home/download/geociencias.shtm).

[3] WMO – World Meteorological Organization (http://www.agteca.com/climate.htm).

[4] SRTM – The Shuttle Radar Topography Mission from National Aeronautics and Space Administration (NASA http://www2.jpl.nasa.gov/srtm/).

Table S2. AUC values for each period of each analyzed area. UPRB – Upper Paraguay River Basin.

	Lowland	Plateau	UPRB
2008-2010	0.872	0.824	0.831
2010-2012	0.874	0.823	0.826
2012-2014	0.849	0.824	0.827
2014-2016	0.853	0.831	0.813

Table S3. Mean of the single variable models, for UPRB (Upper Paraguay River Basin) model.

Variables	2008	2010	2012	2014
Land Cover	1.670E+00	1.08E+00	1.46E+00	1.58E+00
Distance to roads	-5.000E-12	0	0	0
Distance to cities	0	0	0	0
Dry season length	-7.463E-07	-6.17E-07	-7.81E-07	-5.58E-07
Elevation	-2.345E-09	2.76E-09	-1.68E-09	-1.89E-09
Agricultural Potential	0	1.36E-10	1.83E-10	0
Distance to Rivers	0	0	0	0
Cattle	2.123E-08	1.43E-09	7.95E-10	3.12E-09
Permanent Agriculture	0	-3.32E-10	-1.19E-09	-1.24E-09
Annual Crop Agriculture	-5.590E-09	-5.48E-10	3.15E-10	-1.99E-09
Protected Areas	-4.439E-07	0	3.48E-07	-5.63E-07

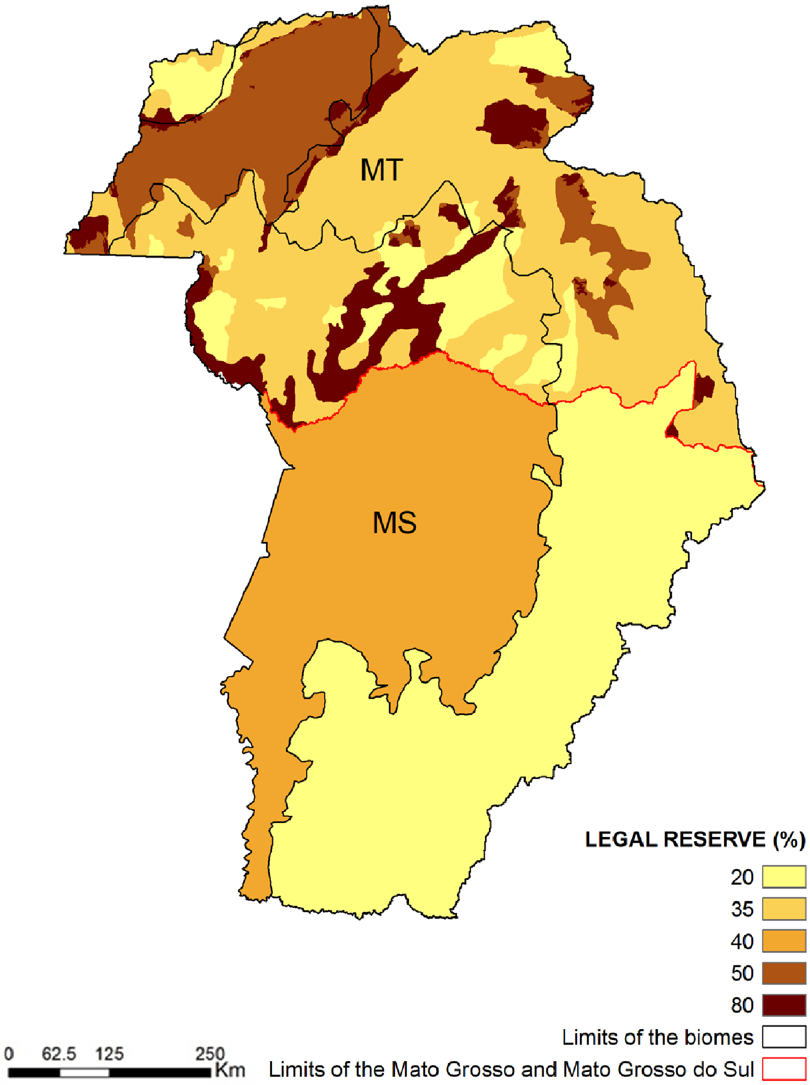

Figure S1. Legal Reserve for property (%) in accordance with Law 12,561 of 2012 ("New Forest Code") regulating different sizes depending on biome and legislation of Mato Grosso do Sul (#Decree 14.273 of 2015), regulating that LR should be 4% for grassland formations and 50% for forest areas of rural properties of Pantanal lowlands. Legend: MS: Mato Grosso do Sul, MT: Mato Grosso.

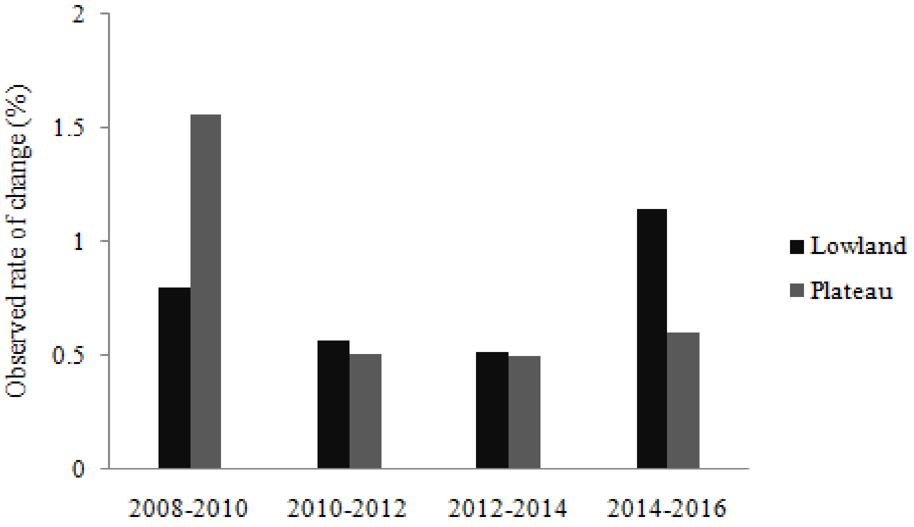

Figure S2. Observed rate of native vegetation loss (%) per year in the lowland and plateau in analyzed periods.

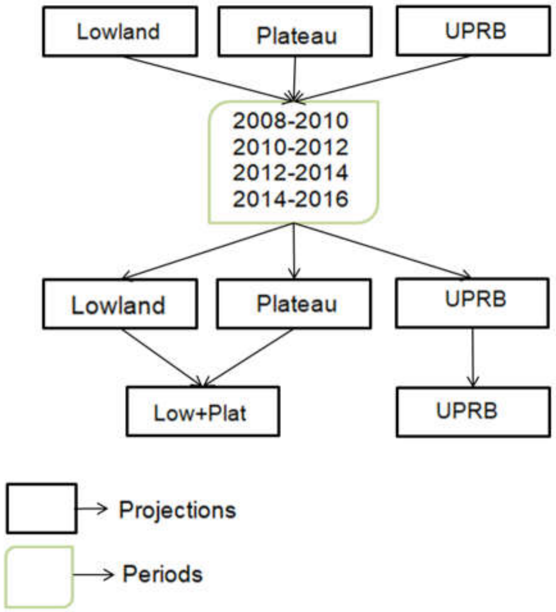

Figure S3. Flowchart of projections for native vegetation loss in the Upper Paraguay River Basin, with Model UPRB (Upper Paraguay River Basin) and Lowland+Plateau models.

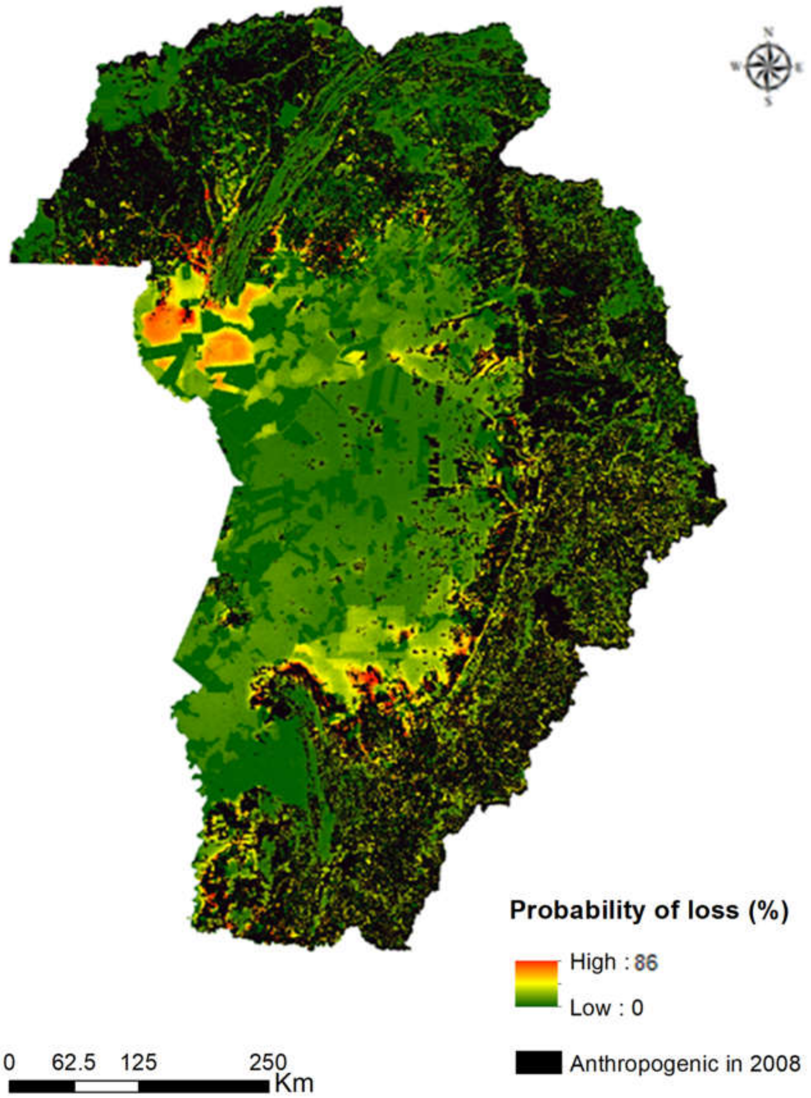

Figure S4. Native vegetation loss predictions for the mean values of four periods (2008-2010, 2010-2012, 2012-2014, and 2014-2016) for the UPRB (Upper Paraguay River Basin) model in 2050.

Chapter 2

The importance of Legal Reserves for protecting the Pantanal biome and preventing agricultural losses

Abstract

Considering scenarios of future changes in land use may help public policies in drafting environmental laws, that when implemented are fundamental to reconcile the demands of multiple land uses, especially in wetlands areas that undergo great anthropogenic pressures. The Pantanal, one of the largest wetlands in the world, has been undergoing rapid land use changes in recent years, and does not yet have any specific environmental legislation on Legal Reserve - LR (minimum percentage of native vegetation cover required for properties) adopted across the whole biome as take place in other Brazilian biomes. The aim of this paper was to generate future vegetation loss scenarios for the Pantanal based on four different scenarios according to different Legal Reserve rates : (i) BAU: *Business as usual*, which considers existing laws: the Native Vegetation Protection Law (NVPL) and the State Decree of Mato Grosso do Sul (14.273 of 2015); (ii) LRE: Legal Reserve extinction due to the recently proposed bill by Flávio Bolsonaro (bill 2362/2019) that extinguishes the requirement of landowners to conserve a percentage of the natural environment on their properties; (iii) LR50: which considers the Pantanal bill (bill 9,950 / 2018) which proposes 50% of the RL for the lowland Pantanal; and (iv) LR80: our proposed levels of 80% of LR for the Pantanal lowlands and 35% for the Pantanal plateau, based in the requirements applied into the Amazon basin. Based on native vegetation

loss arising from each scenario, we estimated the expected soil loss and sediment yield to rivers. Our results show that eliminating legal reserves (LRE) would increase native vegetation loss in the Pantanal by as much as 139% when compared to the BAU scenario, whereas increasing legal reserve levels would reduce conversion rates by 29% (LR80). The reduction of LR rates will increase soil erosion and sediment yield in the Pantanal by up to 7% and 10%, respectively, compared to BAU, where more than 90% of the sediment transported to the Pantanal lowland came from the plateau. The LR80 scenario forecasts a reduction in soil nutrient replacement costs by 10% compared to BAU, while in the LR50 these costs scenario decreases by 1.5%. The LRE, on the other hand, scenario foresees an increase of 8% the nutrient replacement expenditures when compared to the BAU. Our results show that abolishing current protections would have substantial impacts on avulsion processes, increase socioeconomic costs and negative impacts for biodiversity conservation for large areas of the Pantanal. Our results show that keeping the Legal Reserve is important to avoid biodiversity losses and ecosystem goods and services losses, including for the region's agriculture.

Introduction

Scenario modeling is an important tool to foresee how nature responds to different pathways of future human development and policy choices (Ferrier et al. 2016, Rosa et al. 2017). Land cover and land use change (LCLUC) rates tend to decrease when sustainable production incentive policies are made, and when control policies are implemented (Boucher et al. 2013, Stickler et al. 2013), especially in wetlands, which are under great anthropogenic pressure particularly associated with LCLUC globally (Millennium Ecosystem Assessment 2005). Moreover, it can help to overcome the current challenge of reconciling biodiversity and agricultural production in the world (Martinelli & Filoso 2009, Phalan et al. 2019).

To ensure the protection of the natural environment in Brazil, several laws have been proposed, with the latest and most important being the Native Vegetation Protection Law (NVPL – Lei de Proteção da Vegetação Nativa, in Portuguese, known as the "New Forest Code") which apply for private properties representing 44% of Brazil continental area (Sparovek et al. 2019). It requires that landowners set aside a minimum percentage of vegetation cover in their farms (Legal Reserve - LR). However, NVPL does not establish a LR value for wetlands. In addition, the current Brazilian government has shown signs of weakening environmental laws (e.g. bill 2,362/2019, which waives the requirement of rural owners to preserve the Legal Reserve of their properties) (Abessa et al. 2019, Artaxo 2019, Kehoe et al. 2019, Zeidan 2019).

The Pantanal, one of the largest wetlands in the world, considered a hotspot of ecosystem services (Costanza et al. 1997), has no specific legislation on LR, although the creation of its specific legislation was foreseen in the Federal Constitution for almost 30 years. In addition to the legal violation of three decades since NVPL came into force in 2012, it designated the Pantanal as a restricted use area (NVPL article 10), allowing its environmentally sustainable use. However, it does not define the concept of restricted use (Tomás et al. 2019), opening up a gap, and leading to risks and missed opportunities for conservation. This is because some wetlands such as the Pantanal are dynamic systems, dependent on the flood pulse of the watershed, making it difficult to define the minimum LR. Created in 2018 to fill this gap, bill 9,950 aims to protect and generate the sustainable use of the Pantanal biome, and suggests that agricultural land in the Pantanal should maintain 50% of the LR.

The Pantanal is part of the Upper Paraguay River Basin (UPRB), which is formed by the lowland (Pantanal) and plateau (Cerrado and Amazon biomes), where the main rivers and springs that form the lowland originate in the plateau, resulting in two areas with great functional and ecological interdependence, but belonging to two different biomes (Assine 2005, Roque et al. 2016). The region underwent a major intensification of land use over the last 30 years, mainly in the plateau, which in 2016 had 61% of the land as anthropogenic use, against 13% in the lowlands (SOS Pantanal et al. 2017). Vegetation loss, mainly on the plateau, generates large environmental impacts on lowlands, such as an increase in sediment flow of up to 191% and water discharge of up to 82%, which can lead to significant changes in flood dynamics, and ecosystem services (Bergier 2013) affecting the appropriate functioning of the whole biome. A famous example is the Taquari River, which receives sediments yielded by the plateau areas and results in the silting and disruption of its banks, which leaves thousands of hectares of land permanently under water (Bergier & Assine 2016). In addition to changing the Pantanal's flood pulses and interfering with the biome's dynamics, sediment loading from the plateau to the lowland has major social and economic effects in the region, such as death of livestock, and makes the land unproductive (Galdino et al. 2006). Its control is fundamental for agricultural development, showing the importance of reconciling agriculture and conservation (Phalan et al. 2011).

Sediment control is one of the main environmental services of natural systems and process control in wetlands (Hassan et al. 2005). Consequently, the relationship between the plateau and its lowland area is mostly mediated by water fluxes and sediment yield, which is a function of several factors including native vegetation cover (Borreli et al. 2017). In this context, it is paramount to estimate whether native vegetation loss may change the functioning of the whole biome given the new Brazilian political scenario. Therefore, the objective of this study is to construct four different scenarios of vegetation loss (see the methods section for further description) according to implemented law in the UPRB: (i) *Business as usual* (BAU), (ii) Legal Reserve extinction (LRE), (iii) Legal Reserve of 50% for the Pantanal lowland (LR50); and (iv) suggested values of Legal Reserve of 80% for the Pantanal and 35% for the plateau (LR80) and to estimate soil erosion and sediment yield to discuss the effects of soil loss prediction and deposition considering the link between the plateau and lowland in the UPRB.

Methods

Setting up the scenarios

For the modeling of vegetation loss, soil loss and sediment yield, we defined four scenarios: (i) *Business as usual* (BAU), which projects the conversion of LCLUC based on the maintenance of trends that occurred in recent years (2008-2016), considering LR rates set forth in the NVPL and State Decree of Mato Grosso do Sul (14,273 of 2015); (ii) Legal Reserve extinction (LRE), which projects the LCLUC based on the maintenance of trends that have occurred in recent years (2008-2016) and considering that there is no obligation of legal reserves in the properties (as proposed by bill #2,362/2019); (iii) suggested values of a Legal Reserve of 50% for the Pantanal (LR50), which simulates the LCLUC (considering the bill #9,950/2018 that proposes 50% LR rates for the Pantanal); and (iv) considering LR rates for the Amazon (80% for forest areas and 35% for Savannas), we propose a Legal Reserve of 80% for the Pantanal lowland and 35% for the plateau (LR80), which simulates the LCLUC considering the suggested LR rates for the UPRB (Figure 1).

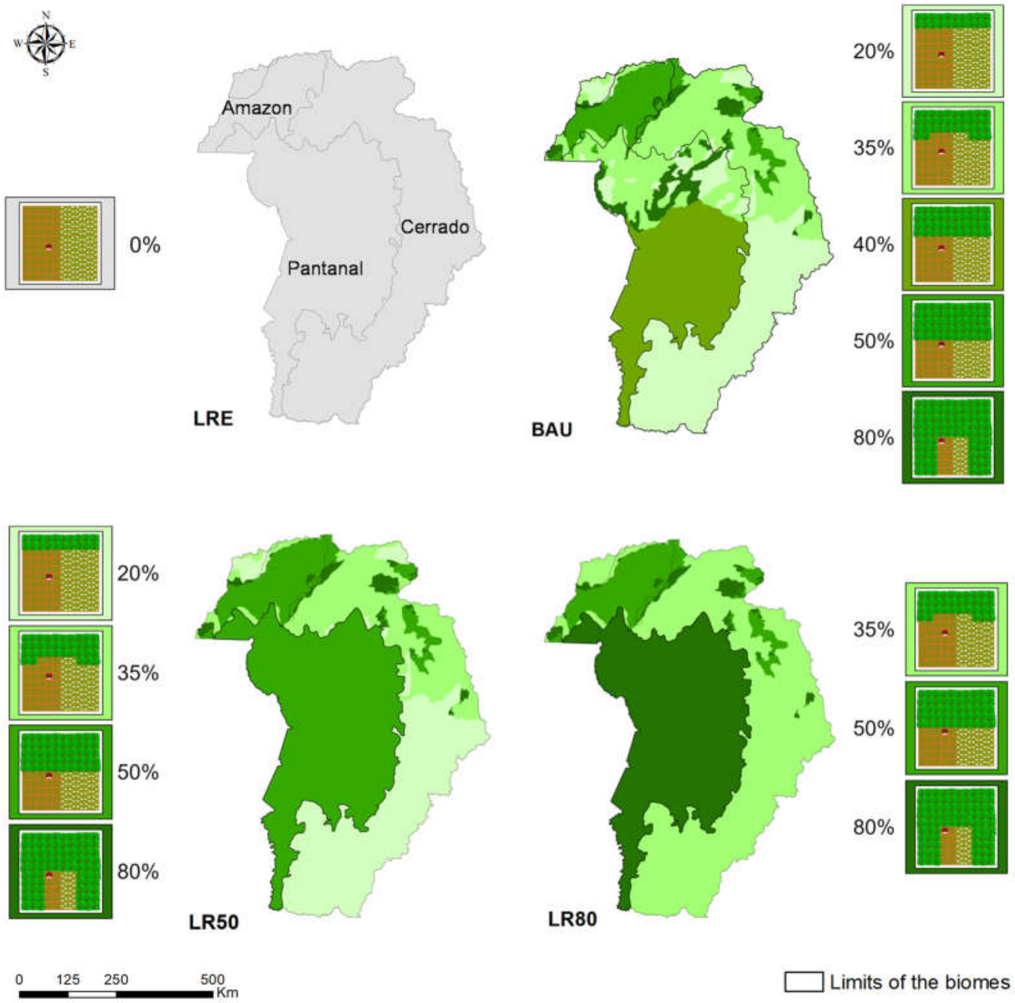

Figure 1. Definition of scenarios for modeling native vegetation loss, soil loss, and sediment yield at Upper Paraguay River Basin. Legend: (LRE) Legal Reserve extinction as proposed by bill #PL 2,362/2019 ; (BAU) *Business as usual* considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LR50) 50% Legal Reserve for the Pantanal considering the bill # 9,950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR rates as in the Amazon.

Modeling the native vegetation loss

We used the results from Chapter 1 to determine the drivers of vegetation loss and to project the conversion of native vegetation to anthropogenic vegetation by 2050 into the UPRB. This model showed that plateau and lowland have different drivers of vegetation loss and, therefore, analyses must be carried out separately in the two areas. The study showed that cattle density, agriculture extension, agricultural potential, and dry season length were drivers of vegetation loss both on the plateau and in the lowland. However, the distance to roads and rivers and elevation were identified as drivers only in the lowland and the distance to cities only in the plateau. For more details on the model, please see Chapter 1.

Soil loss estimation

To calculate the soil loss on 250x250 m spatial resolution, we used the Invest 3.7.0 (The Natural Capital Project: Stanford, USA), which is based on the Universal Soil Loss Equation (USLE) Eq. 1 (Wischmeier & Smith 1978):

$$A = R * K * LS * C * P \qquad \text{Eq. 1}$$

In which: A is the average soil loss per unit of area (t ha^{-1} year^{-1}); R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}); K is the soil erodibility factor (t h MJ^{-1} mm^{-1}); LS is the topographic factor (dimensionless); C is the soil use and management factor (dimensionless) and P is the conservation dimension factor (dimensionless).

We used the rainfall erosivity (R-factor) developed by Almagro et al. (2017), which computed the R-factor (Figure 2a) across Brazil by applying observed precipitation data for the period of 1980 through 2013. Their results were validated using local R-Factor values, obtaining suitable performance values of R², RMSE, NSE of 0.91, 2,350 MJ mm ha^{-1} h^{-1} yr^{-1}, 0.53, respectively.

We obtained the K-factor values (Figure 2b) of the local studies carried out on different types of Brazilian soils. Table 2 shows the classes of soils according to the Brazilian Soil Classification System (SiBCS), soil erodibility values and their respective bibliographic sources. We then assign these K-factor values to the soil class map developed for UPRB.

Table 2. Soil Erodibility (K) in the Upper Paraguay River Basin.

Brazilian Classification	K-factor (t ha h ha^{-1} MJ^{-1} mm^{-1})	Source
Red Argosols	0.0228	(Mannigel et al. 2008)
Red-Yellow Argosols	0.0466	(Mannigel et al. 2008)
Cambisols	0.0254 - 0.0441	(Mannigel et al. 2008)
Chernozems	0.0309	(Silva et al. 2011)
Spodosols	0.3267	(Mannigel et al. 2008)
Haplic Gleysols	0.0044	(Mannigel et al. 2008)
Yellow Latosols	0.0570	(Mannigel et al. 2008)
Red Latosols	0.0061- 0.0263	(Mannigel et al. 2008)
Red-Yellow Latosols	0.0112	(Mannigel et al. 2008)
Litholic Neosols	0.0196	(Pasquatto 2016)
Quartzarenic Neosols	0.1448	(Mannigel et al. 2008)
Regolithic Neosols	0.1238	(Ruthes et al. 2012)
Nitisols	0.0081 - 0.0355	(Mannigel et al. 2008)
Organosols	0.0317	(Mannigel et al. 2008)
Other	0.0317	(Mannigel et al. 2008)
Plinthosols	0.0170	(Martins et al. 2010)
Vertisols	0.0400	(Silva et al. 2011)

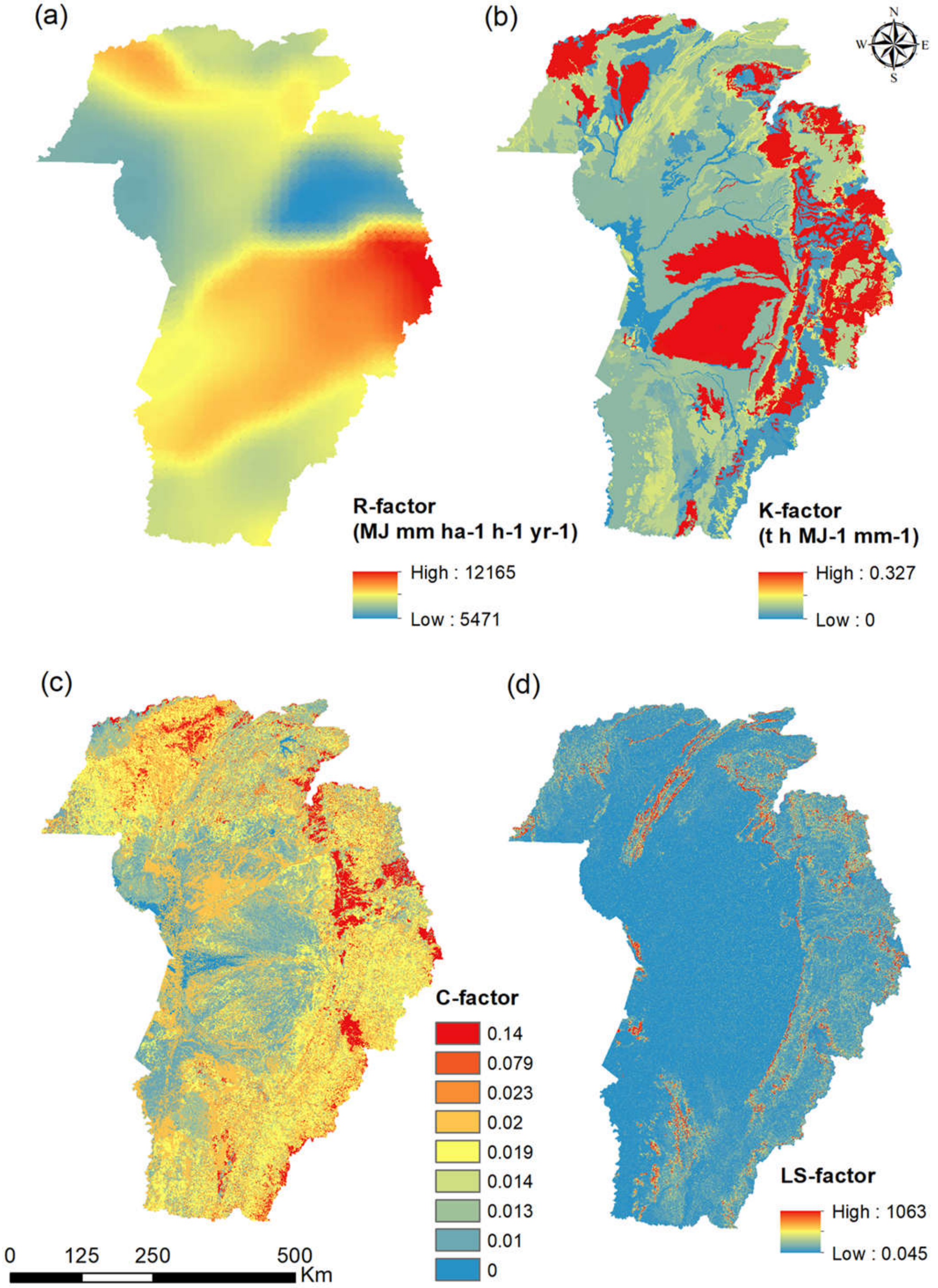

Figure 2. Spatialization of (a) R-factor, (b) K-factor, (c) C-factor for land use in the year 2017, and (d) LS-factor (topographic factor) values in the Upper Paraguay River Basin.

To calculate the LS factor, we used a 30-m digital elevation model (DEM) obtained from the Geomorphometric Database of Brazil (TOPODATA - http://www.dsr.inpe.br/topodata/) that provides data from the South American altimetry and by-products, then clipped it to the UPRB area and resampled to 250 m, to have the same resolution as the other data.

The LS-factor (Figure 2d) was computed for each pixel in the DEM, where the L factor is expressed as Desmet & Govers (1996):

$$LS_i = S_i \frac{\left(A_{i-in} + D^2\right)^{m+1} - A_{i-in}^{m+1}}{D^{m+2} \cdot x_i^m \cdot (22.13)^m} \qquad \text{Eq. 2}$$

where S_i is the slope factor for grid cell calculated as a function of slope radians θ.

$S = 10.8 \cdot Sin\ (\theta) + 0.03$, where $\theta < 9\%$ Eq. 3

$S = 16.8 \cdot Sin\ (\theta) + 0.50$, where $\theta < 9\%$ Eq. 4

A_{i-in} is the contributing area m^2 at the inlet of a grid cell which is computed from the d-infinity flow direction method; D is the grid cell size (m); $X_i = |Sin\ \alpha_i| - |Cos\ \alpha_i|$, where α_i is the aspect direction for grid cell i; m is the length exponent of the RUSLE.

In the RUSLE, (m) varies according to the ratio of the rill and inter-rill erosion (β).

$m = 0.2$ for slope $\leq 1\%$ Eq. 5

$m = 0.3$ for $1\% <$ slope $\leq 3.5\%$ Eq. 6

$m = 0.4$ for $3.5\% < \text{slope} \leq 5\%$ Eq. 7

$m = 0.5$ for $5\% < \text{slope} \leq 9\%$ Eq. 8

$m = \beta /1+ \beta$ Eq. 9

where $\beta = \sin \theta/0.0986/3 \sin \theta^{0.8} + 0.56)$ for slope $\leq 9\%$ Eq. 10

We used the C-factor values (Figure 2c) obtained by experimental plot studies developed in Brazil (see Oliveira et al. 2015). These C-factors were provided by soil erosion plots under natural rainfall and different land cover and land use in Brazil (Table 3, Figure 2c). Land use classes were taken from MapBiomas 3.0 (http://mapbiomas.org/). For the vegetation loss scenarios up to 2050, we consider that the areas under anthropogenic use were converted into pasture and agriculture mosaics, since it was not possible to identify the class of land use that will be converted. The P factor is related to the conservation practices used in the region for each use and land cover, and since the region does not present conservation practices, we attribute the value 1.

Table 3. C-Factor values assigned to each land use in the Upper Paraguay River Basin.

Land use	C
Forest formation	0.020
Savanna formation	0.013
Forest plantation	0.140
Wetlands	0.013
Grassland Formation	0.010
Pasture	0.019
Agriculture	0.140
Mosaic of agriculture and pasture	0.079
Urban Infrastructure	0.023
Water	0

Source: Oliveira et al. 2015.

Sediment Delivery Ratio (SDR)

We used the SDR module from Invest 3.7.0 (The Natural Capital Project: Stanford, USA). The SDR is a spatially explicit model that calculates the average annual amount of soil loss for each pixel. We spatialize the results of the SDR model at the level of the 6th order sub-basin of ottobasins of the National Water Agency (Agência Nacional das Águas - ANA, in Portuguese) (http://www.ana.gov.br/bibliotecavirtual/solicitacaoBaseDados.asp). The UPRB area has 8,130 ottobacias of the 6th order. As a result, the SDR provides the sediment yield to streams and the annual loss of soils in the ton basin^{-1}. After calculating soil loss and sediment yield for the four scenarios, we compared the soil loss and sediment yield based on current land use (2017).

Economic cost of soil erosion

To calculate the economic costs of soil erosion, we consider the soil nutrient replacement costs in the areas of agriculture and livestock per year (Marques & Pazzianotto 2004), in each scenario, given by the following equation Eq. 11:

$$CR = \sum_{n-1}^{4} Pn \times Qn \qquad \text{Eq. 11}$$

In which: CR = replacement costs in \$/t, Pn = fertilizer price in \$/t and Qn = fertilizer quantity in t.

This methodology takes into account the area occupied by pasture and agriculture within the basin and the amount of soil lost, in addition to the current prices of the ton of fertilizers.

Results

Loss of native vegetation

We found an average vegetation loss (±sd) of 10.0% (±2.0%) for BAU and LR50, 13.4% (±0.9%) for LRE, and 7.9% (±0.2%) for LR80 between 2016 and 2050 for the plateau. For the lowland, the rates of vegetation loss are lower than in the plateau, in which 3.0% (±0.2%) is for BAU, 3.4% (±0.2%) for LRE, 2.6% (±0.1%) for LR50, and 2.3% (±0.1%) for LR80 between 2016 and 2050. Considering the basin, vegetation loss by 2050 can reach 14,005 km² in BAU, 32,448 km² in LRE (18,443 > than BAU), 11,375 km² in LR50 (2,630 < than BAU) and 10,005 km² in LR80 (3,000 < than BAU) (Table 4).

Table 4. Average native vegetation loss (±sd) from 2016 to 2050 in the plateau and lowland in each scenario (km²). Legend: (BAU) *Business as usual* considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LRE) Legal Reserve extinction as proposed by bill #PL 2,362/2019; (LR50) 50% Legal Reserve for the Pantanal considering bill # 9,950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR rates as in Amazon.

	BAU	**LRE**	**LR50**	**LR80**
Lowland	6,045 (±362)	7,932 (±536)	3,415 (±197)	3,067 (±133)
Plateau	7,960 (±1,574)	24,516 (±1,719)	7,960 (±1,574)	6,938 (±1,750)
UPRB	14,005 (±1,936)	32,448 (±2,255)	11,375 (±1,771)	10,005 (±1,883)

In 2016, the plateau had 61% of anthropogenic land use and the lowland 13%. The accumulated rates of vegetation loss show that in 2050 the plateau area can reach 65.0% in BAU and LR50, 72.3% in LRE (7.3% > than BAU), and 64.0% in LR80 (1.0% < than BAU). In the lowland, these values can reach 17.0% of the anthropogenic land use by the BAU, 18.2% by LRE scenario (1.2% > than BAU), 15.5% by LR50 (1.5% < than BAU) and 15.0% by LR80 (2.0% < than BAU). We map the probabilities of vegetation loss for each scenario (Figure 3), and in all scenarios the highest probability of loss was found in the plateau and transition regions between plateau and lowland, described as Arc of vegetation loss in the Pantanal (Chapter 1).

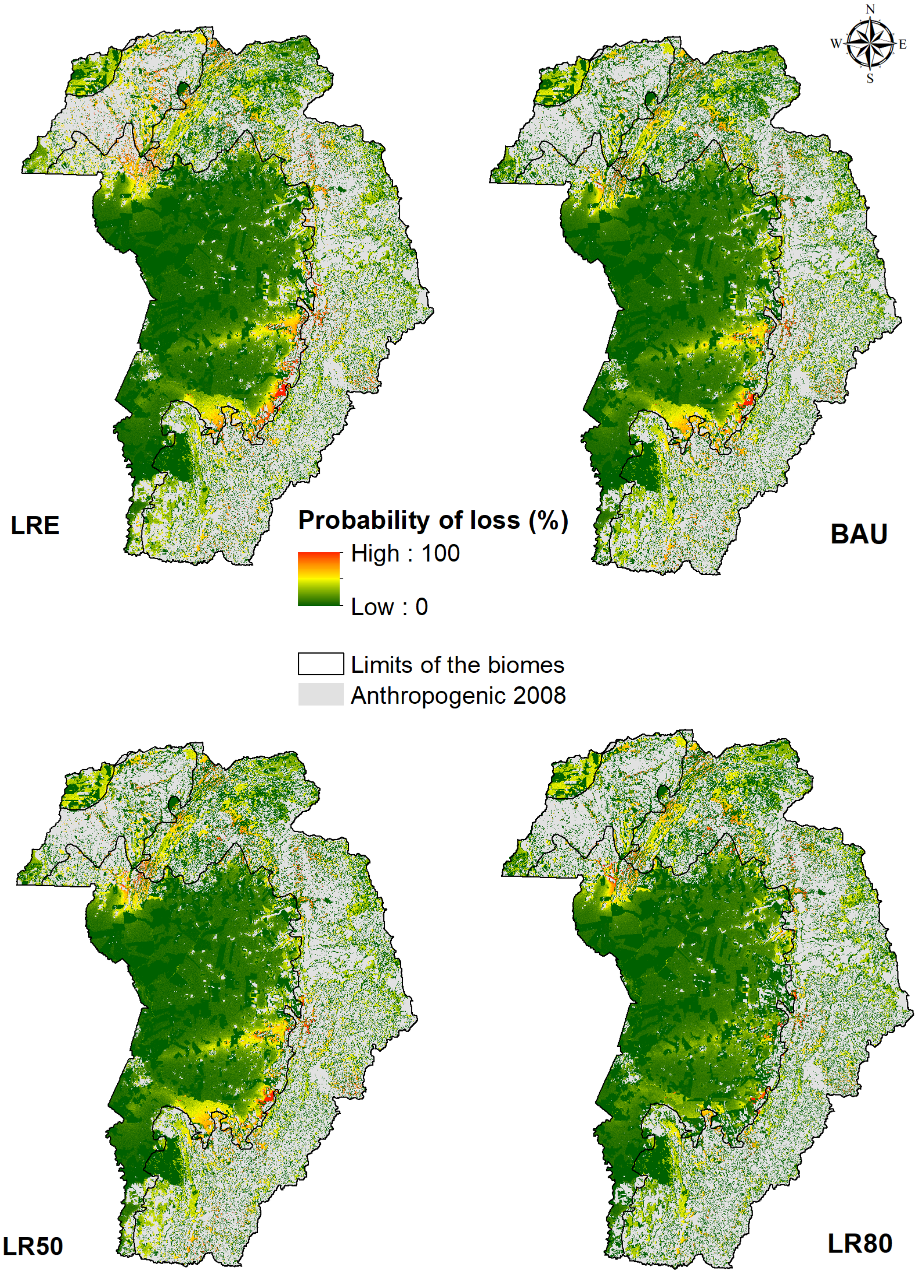

Figure 3. Probability of native vegetation loss in the Upper Paraguay River Basin by scenario. Legend: (LRE) Legal Reserve extinction as proposed by bill #PL 2,362/2019 ; (BAU) *Business as usual* considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LR50) 50% Legal Reserve for the Pantanal considering bill # 9,950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR rates as in Amazon.

Soil loss and economic costs

Our projections showed that there is an increase of the average annual soil loss in all scenarios in relation to the current values (Figure 4 and Figure S2). In the plateau, the BAU and LR50 scenarios predict an average annual soil loss of 248 Mt yr^{-1} between 2017 and 2050, 289 Mt yr^{-1} for the LRE (41 Mt yr^{-1} > than BAU), and 241 Mt yr^{-1} for the LR80 (7 Mt yr^{-1} < than BAU) (Figure 4b). For the lowland, there is a soil loss of 31 Mt yr^{-1} by BAU, 38 Mt yr^{-1} by LRE (7 Mt yr^{-1} > than BAU), 18 Mt yr^{-1} in LR50 (13 Mt yr^{-1} < than BAU), and 16 Mt yr^{-1} for LR80 (15 Mt yr^{-1} < than BAU) (Figure 4b and Figure S2). Soil loss values were presented in millions of tons because they refer to a loss in the whole area (plateau and lowland) and not per hectare. The decrease of the LR size is proportional to the increase of sediment export in the basin (Figure 5), with a significant decreasing around the Taquari river, the most degraded area in the lowland. In the center of the maps, we highlight the River Taquari's inlets changing form sediment export of 11-50 t ha^{-1} yr^{-1} (in yellow, Figure 5) to 6-10 t ha^{-1} yr^{-1} from LRE and BAU to LR50 and LR80 scenarios (in light green, Figure 5).

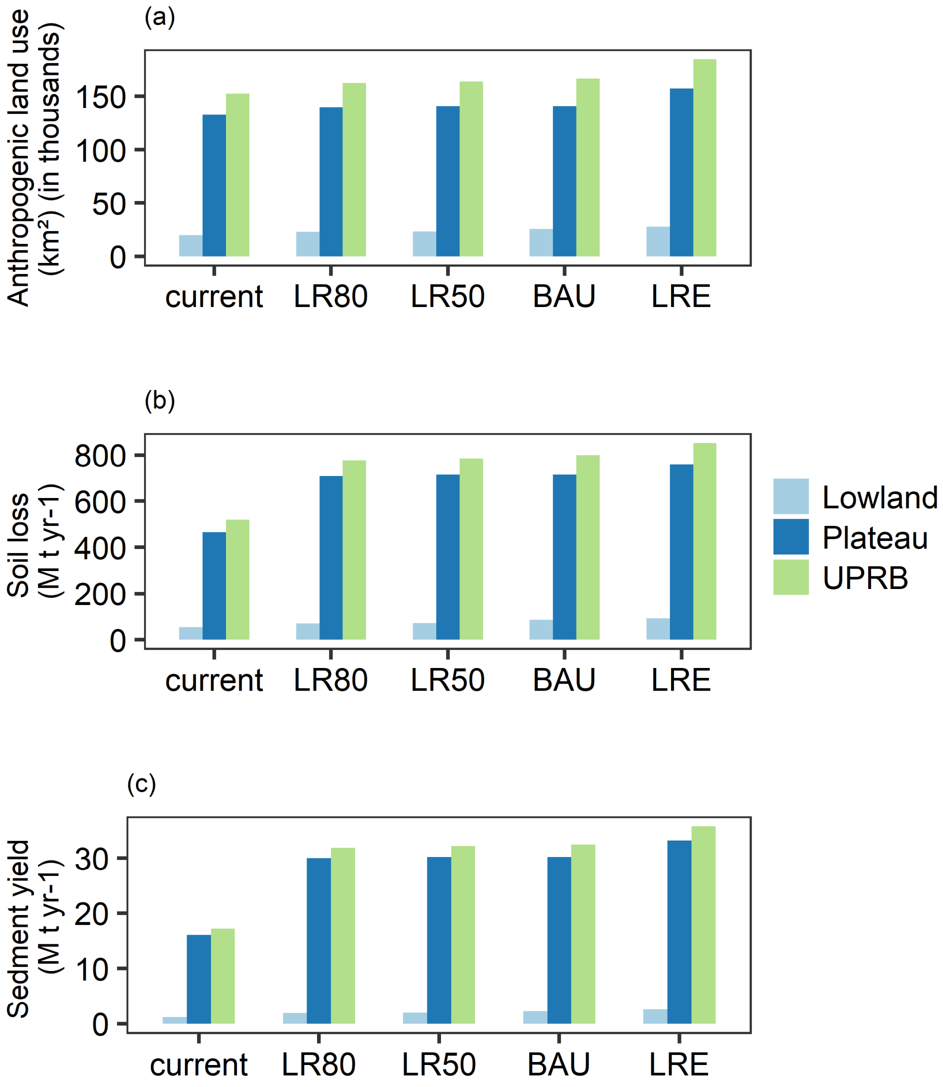

Figure 4. Anthropogenic land use (a), soil loss (b), and sediment yield for (c) for Lowland, Plateau, and Upper Paraguay River Basin. Legend: (LRE) Legal Reserve extinction as proposed by bill #PL 2,362/2019; (BAU) *Business as usual* considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LR50) 50% Legal Reserve for the Pantanal considering the bill # 9,950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR rates as in the Amazon.

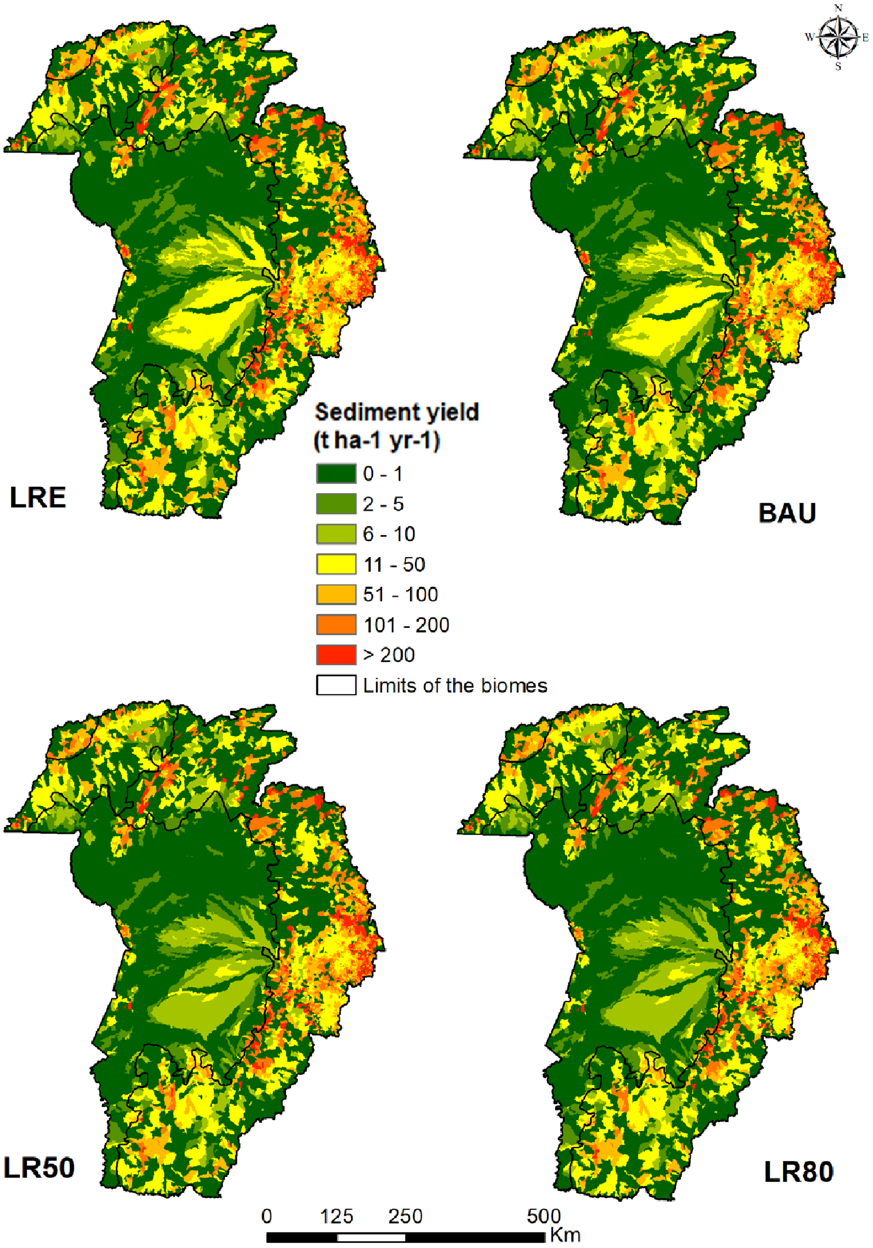

Figure 5. Projection of sediment yield (tons per hectare per year) in the Upper Paraguay River Basin by each scenario. Legend: (LRE) Legal Reserve extinction as proposed by bill #PL 2,362/2019; (BAU) *Business as usual* considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LR50) 50% Legal Reserve for the Pantanal considering bill # 9,950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR rates as in the Amazon.

The BAU scenario predicts that by 2050 the soil nutrient replacement costs will be $15.5 million. From these, $4 million for pasture areas and $11 million for UPRB's agricultural areas (Figure 6). The LRE scenario foresees an increase in 8% of the nutrient replacement expenditures of the soil when compared to the BAU resulting in a magnitude of U$16.7 increasing economic loss. On the other hand, the LR80 scenario predicts the decrease of this value by 10% (13.9 million) and the LR50 scenario foresees the decrease by 1.5% (15.2 million) (Figure 6).

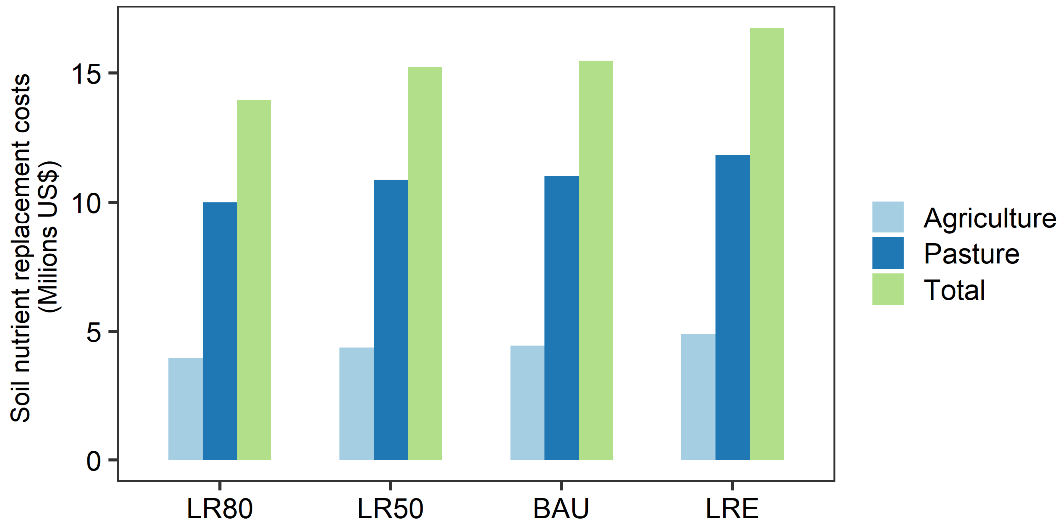

Figure 6. Soil nutrient replacement costs in agriculture and pasture areas in the Upper Paraguay River Basin in each scenario. Legend: (LRE) Legal Reserve extinction as proposed by bill #PL 2,362/2019; (BAU) *Business as usual* considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LR50) 50% Legal Reserve for the Pantanal considering the bill # 9,950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR rates as in the Amazon.

Sediment yield

The sediment yields in the plateau increase from 2017 to 2050 in the BAU and the LR50 scenarios is 14 Mt yr-1, 17 Mt yr-1 for LRE, and 13 Mt yr-1 for LR80 (Figure 4c and Figure S3). In the lowland, the BAU scenarios predict an increase of 1.4 Mt yr-1, 1.7 Mt yr-1 in LRE, 831,100 yr-1 in LR50, and 742,000 yr-1 for LR80 from 2017 to 2050 (Figure 4c and Figure S3). More than 90% of the sediment deposited in the Pantanal originates on the plateau (Figure 5).

Discussion

Loss of native vegetation

Our work supports the key role of the legal reserve not only for biodiversity conservation but also for agricultural production (Metzger et al. 2019). We have shown that conserving the legal watershed reserve is key to maintaining environmental services such as sediment regulation in the wetlands such as the Pantanal. Our results show that the extinction of Legal Reserves in properties can increase the rate of vegetation loss by 130% by 2050 in UPRB (31% in the lowlands and 207% in the plateau) compared to the current laws (BAU). On the other hand, the bill that proposes 50% of the rural properties as LR in the lowlands, would reduce the loss of vegetation by 44% in this area, and would not affect the vegetation loss on the plateau. Following our scenario of 80% LR for the lowlands and 35% for the plateau, there would be a 30% reduction of native vegetation loss in the basin (UPRB), decreasing 50% for the lowlands and 23% for the plateau.

Our results show that increasing Legal Reserve rates would decrease vegetation loss in the basin but that the 50% rate for the lowlands is not enough to reduce vegetation loss in the region and would decrease very few of the current rates. In addition, the LR50 scenario considers the increase in LR rates only in the lowlands, while the plateau would maintain its high loss rates. Meanwhile, the scenario of suggesting 80% LR for the lowlands and 35% for the plateau, would avoid larger vegetation losses, besides considering the plateau, where the suppression of the native vegetation has a direct influence on the dynamics of the lowland. On the other hand, the extinction of LR would bring a very large increase in vegetation loss (reaching increasing values of 207%), which may have very severe consequences on the ecosystem services of the Pantanal and on the appropriate functioning of the Pantanal. In addition, simulated scenarios provided here considered vegetation loss trends based on historical rates. Hence, the extinction of the legal reserve expected to further increase land conversion rates, which makes the scenario even more pessimistic than the LRE presented here. Besides, our model does not predict in which land use the native vegetation will be converted. However, considering the dynamics of occupation of the UPRB, we argue that it will be converted into a mosaic of pasture and agriculture.

Soil loss, economic costs and sediment yield

Soil erosion is considered a global threat and has an impact beyond where it takes place. The consequences of soil erosion are diverse, such as the loss of organic matter and soil nutrients (Bennett 1933, Morgan 2005, Lal 2006), directly affecting agricultural productivity and livestock production, reaching about US $ 2.4 billion per year of losses in Brazil (Silva et al. 2011). In addition, it causes loss of the value of agricultural land (Gardner & Barrows 1985), pollution of water resources (Clark 1985) and flooding of lands and sediments (Pimentel et al. 1995, Marques 1998).

In addition to physical, chemical, and biological losses, soil erosion causes economic losses that can be expressed in terms of the costs incurred by farmers and society to repair the damage resulting from this process (Telles et al. 2011). Soil loss owing to erosion tends to increase production costs in the medium and long term, with increased demand for lime and fertilizer applications and reduced machine operating efficiency, incurring costs to control the situation (Uri 2000, Bertoni & Lombardi Neto 2008). Our results show that the extinction of Legal Reserves leads to a 7% increase in soil loss and a consequent 8% increase in costs to replenish soil nutrients compared to the BAU scenario. On the other hand, increasing Legal Reserve rates, as in the LR80 scenario can decrease soil loss by 3% and 10% nutrient replacement costs compared to the BAU scenario. This confirms that in addition to what has already been shown that extensive destruction of natural vegetation is not a requirement for increased agricultural production in Brazil (Foley et al. 2011, Strassburg et al., 2014, Metzger et al. 2019), the legal reserve extinction would significantly affect agriculture practices given the relationship between the plateau and the lowlands in the UPRB.

The evaluation of erosion, based on the concept of nutrient replacement, is considered as a variable of the value of the good or service (Hartwick 1977), not considering damage to other environmental goods and services such as biodiversity loss, water quality and sedimentation (Stevens et al. 1991). However, the present work shows the urgent need to prevent and control soil degradation processes. Hence, data on erosion costs are of fundamental importance, especially in developing countries, which are generally dependent on primary production of agriculture goods (Telles et al. 2011).

Brazil is considered the second country among the hotspots of soil erosion in the world after China (Borrelli et al. 2017). To reduce soil erosion and mitigate its social costs, there are a number of policy options available to induce farmers to adopt conservation practices, including payment for ecosystem services, biodiversity-based product value chains, protected areas, community-based management, and education (Uri & Lewis 1988, Sone et al. 2019).

Our findings show a great change in soil loss in a particular critical area, the Taquari river. The sediment transport to rivers is one of the main environmental and socioeconomic problems of the Pantanal, especially in the Taquari River (Adámoli 1985, Bergier & Assine 2016). The region can be seen in Figure 5 owing to a great difference with high soil loss in the central part of the map from LRE and BAU in respect to LR50 and LR80 scenarios. In recent years, it has burst its banks, forming new beds, called "*arrombados*" and producing thousands of acres of seasonal land (Galdino et al. 2006). This has caused the death of animals and vegetation not adapted to the floods, as well as leaving people homeless and altering the dynamics of the biome. Taquari was recently considered a priority area for restoration in a public call (Art ist, 2nd, of IBAMA/Portaria # 3,447/2018). However, since the formation of the new government, these restoration projects have been suspended because of Presidential Decree No. 9760/19, which is another current environmental setback (SOBRE 2019). As shown, this area is a priority for restoration actions. Therefore, we claim that our results are taken into account by decision makers and policy makers to act in the best interest of conserving, while maintaining the environmental services that native vegetation provides for the proper functioning of this unique ecosystem.

In all simulated scenarios, more than 90% of the sediments transported to the Pantanal are produced in the plateau, showing the importance of the relationship between plateau and lowland. Besides, we showed how the processes occurring in the plateau have a direct impact on the dynamics of the lowland. This shows the importance of implementing emergency public policies in this area, which apprehends most of its properties with Legal Reserve deficits. Incentive programs should be created for the owners to restore legal reserve liabilities of their properties, as well as enforcement so that the owners follow the legal reserve values set forth in the NVPL. Besides public incentives, international pressure is also an important strategy. Recently, 602 European scientists wrote a letter drawing the European Union´s attention to trade with Brazil only if the country is sustainable, and to comply with environmental and indigenous laws and conventions (Kehoe et al. 2019). In response, a coalition of Brazilian scientists highlighted the great threat for that owing to the bill #PL 2,362/2019 about Legal Reserve extinction and it risks as a likely long-lasting catastrophic impacts on biodiversity, society, jeopardizing climate change mitigation efforts and international conventions (Kehoe et al. 2019, Tomas et al. 2019), such as the Paris Climate Agreement. Hence, considering that both loss of vegetation and soil loss leads to an increase in CO_2 emissions and a decrease in carbon sequestration (Smith et al. 2015, Arneth et al. 2017), our results clearly show how environmental losses can compromise an important proportion of these commitments.

Another recent problem at UPRB is the transport of mud from the Bodoquena plateau to the rivers of the city of Bonito and Jardim, especially the Formoso and Prata rivers (Gaigher 2019). Bonito is the largest ecotourism destination in the world, receiving about half a million tourists each year (Sabino & Andrade 2003). In recent years, after heavy rains, the crystalline river system was affected by mud from the region's agriculture areas, which went from 29.8 thousand hectares to 58.5 thousand in the last five years, mainly occupied by soybean production. Therefore, allowing for continued vegetation loss, and potentially aggravating it by eliminating the need for a Legal Reserve, would contribute to the existing environmental problems in the Pantanal, which may have a strong effect on ecotourism that moves R$ 300 million a year. Our results reinforce the need for implementing Legal Reserve rates that would protect not only the many species that use the Pantanal as their habitat but also prevent major socio-economic losses.

Here, we show that more important than raising the Legal Reserve rates is to prevent Legal Reserves from being extinguished. This extinction would cause irreversible damage to the native vegetation, and consequently the soil erosion and sedimentation in the Pantanal, with far reaching implications in the socioeconomic dynamics of the region. In addition, the need to preserve the plateau can be observed, because it is where most of the sediments carried to the lowland are produced. Investing in passing environmental protection bills for the Pantanal is critical to ensure its sustainability, ecosystem services and conservation.

Conclusion

In this chapter, we discuss how different scenarios of legal reserve rates in the Pantanal can impact vegetation loss by 2050 and the consequences on soil erosion, sediment yield and cost of soil nutrient replacement due to agriculture and pasture. The extinction of the Legal Reserve would result in the loss of more than 32,000 km² of native vegetation in the Pantanal and would increase soil erosion and sediment production, with more than 90% of the sediment transported from the plateau to the lowlands of the Pantanal. The extinction of the Legal Reserve foresees an increase of 8% of the expenses replacing soil nutrients. On the other hand, introducing a 50% or 80% Legal Reserve policy in the region would save 1.5% and 10% of nutrient replenishment costs compared to the "New Forest Code". The results show the importance of using scenarios to support public policies and decision making, especially in times when bills are under discussion in the current Brazilian political scenario, showing the consequences of legal reserve extinction over vegetation and soil loss, and production of sediments. Besides, we show how the slackening of environmental laws can influence not only agricultural losses, but also livestock productivity.

References

Abessa, D., Famá, A., Buruaem, L. 2019. The systematic dismantling of Brazilian environmental laws risks losses on all fronts. Nature Ecology & Evolution, 3, 510–511. https://doi.org/10.1038/s41559-019-0855-9DO

Adámoli, J., Macedo, J., Azevedo, L. G., Madeira N. J. S. 1985. Caracterização da região dos Cerrados. In: Goedert, W. J. (Ed.) Solos dos Cerrados: Tecnologias e estratégias de manejo. pp. 33-74. São Paulo: Embrapa.

Almagro, A., Oliveira, P.T.S., Nearing, M.A., Hagemann, S. 2017. Projected climate change impacts in rainfall erosivity over Brazil. Scientific Reports, 7. https://doi.org/10.1038/s41598-017-08298-y

Arneth, A., Sitch, S., Pongratz, J., Stocker, B. D., Ciais, P., Poulter, B., Bayer, A. D., Bondeau, A., Calle, L., Chini, L. P., Gasser, T., Fader, M., Friedlingstein, P., Kato, E., Li, W., Lindeskog, M., Nabel, J. E. M. S., Pugh, T. A. M., Robertson, E., Vioyy, N., Yue, C., Zaehle, S. 2017. Historical carbon dioxide emissions caused by land-use changes are possibly larger than assumed. Nature Geoscience, 10, 79–84. https://doi.org/10.1038/ngeo2882

Artaxo, P. 2019. Working together for Amazonia. Science, 363(6425), 323. https://doi.org/10.1126/science.aaw6986

Assine, M.L. 2005. River avulsions on the Taquari megafan, Pantanal wetland, Brazil. Geomorphology 70, 357–371.

Bennett, H. H. 1933. The cost of soil erosion. The Ohio Journal of Science, 33, 271-279.

Bergier, I. 2013. Effects of highland land-use over lowlands of the Brazilian Pantanal. Science of the Total Environment, 463, 1060–1066. https://doi.org/10.1016/j.scitotenv.2013.06.036

Bergier I., Assine, M. 2016. Dynamics of the Pantanal wetland in South America. Damià Barceló, Andrey G. Kostianoy, ISBN: 978-3-319-18734-1

Bertoni, J, Lombardi Neto, F. 2008. Conservação do solo. São Paulo: Ícone.

Borrelli, P., Robinson, D. A., Fleischer, L. R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Van Oost, K., Montanarella, L., Panagos, P. 2017. An assessment of the global impact of 21st century land use change on soil erosion, Nature Communications, 8, 1–13. https://doi.org/10.1038/s41467-017-02142-7

Boucher, D., Roquemore, S. & Fitzhugh, E. 2013. Brazil's success in reducing deforestation. Tropical Conservation Science, 6(3), 426-445. https://doi.org/10.1177/194008291300600308

Clark, E. H. 1985. The off-site costs of soil erosion. Journal of Soil and Water Conservation, 40, 19-22.

Costanza, R., d' Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., … van den Belt, M. 1997. The value of the world's ecosystem services and natural capital. Nature, 387(6630), 253–260. https://doi.org/10.1016/S0921-8009(98)00020-2

Desmet, P. J. J., Govers, G. 1996. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. Journal of Soil and Water Conservation, 51, 427–433.

Ferrier, S., Ninan, K. N., Leadley, P., Alkemade, R., Acosta, L. A., Akçakaya, H. R., Brotons, L., Cheung, W. W. L., Christensen, V., Harhash, K. A., Kabubo-Mariara, J., Lundquist, C., Obersteiner, M., Pereira, H. M., Peterson, G., Pichs-Madruga, R., Ravindranath, N., Rondinini, C. Wintle, B. A. 2016. (eds) The methodological assessment report on scenarios and models of biodiversity and ecosystem services (IPBES).

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M. 2001. Solutions for a cultivated planet. Nature, 478, 337

Gaigher, C. 2019. Turbilhão de lama ameaça águas cristalinas do Rio da Prata, em Mato Grosso do Sul. 07 Apr. 2019. TV Morena. Retrieved from: https://g1.globo.com/ms/mato-grosso-do-sul/noticia/2019/04/07/turbilhao-de-lama-ameaca-aguas-cristalinas-do-rio-da-prata-em-mato-grosso-do-sul.ghtml

Galdino, S., Vieira, L. M., Pelegrin, L. A. 2006. Impactos ambientais e socioeconômicos na Bacia do Rio Taquari – Pantanal. Corumbá: Embrapa Pantanal.

Gardner, K., Barrows, R. 1985. The impact of soil conservation investments on land prices. American Journal of Agricultural Economics, 67, 943-947.

Hartwick, J. 1977. Intergenerational equity and the investing of rents of exhaustible resources. American Economic Review, 67(5), 972-974.

Hassan, R., Scholes, R., Ash, N. 2005. Ecosystems and human well-being. Current state and trends. Washington, DC: Island Press.

IBAMA – Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. 2018. Portaria Nº 3.444, de 27 de novembro de 2018. 3º Chamamento Público do Ibama Sede para a conversão indireta de multas. Retrieved from http://www.in.gov.br/materia/-

/asset_publisher/Kujrw0TZC2Mb/content/id/52250607/do1-2018-11-28-portaria-n-3-447-de-27-de-novembro-de-2018-52250374

Kehoe, L., Rei, T., Virah-Sawmy, M., Balmford, A., Kuemmerie T. 2019. Make EU trade with Brazil sustainable. Science, 364(6438) 341. https://doi.org/10.1126/science.aaw8276

Lal, R. 2006. Managing soils for feeding a global population of 10 billion. Journal of the Science of Food and Agriculture, 86, 2273-2284. https://doi.org/10.1002/jsfa.2626

Mannigel, A. R., E Carvalho, M. D. P., Moreti, D., Medeiros, L. D. R. 2008. Fator erodibilidade e tolerância de perda dos solos do Estado de São Paulo. Acta Scientiarum Agronomy, 24, 1335. https://doi.org/10.4025/actasciagron.v24i0.2374

Marques, J.F. 1998. Costs of soil erosion due to their on-site and off-site effects in the area of agricultural production. Revista Brasileira de Economia e Sociologia Rural, 36, 61-79.

Marques, J. F., Pazzianotto, C. B. 2004. Custos Econômicos da Erosão do Solo: estimativas pelo método do custo de reposição de nutrientes. Simulação do Custo Econômico da Reposição do Solo. Embrapa Jaguariúna.

Martinelli, L.A., Filoso, S. 2009. Balance between food production, biodiversity and ecosystem services in Brazil: a challenge and an opportunity. Biota Neotropica, 9(4). http://dx.doi.org/10.1590/S1676-06032009000400001

Martins, S. G., Silva, M. L. N., Avanzi, J. C., Curi, N., Fonseca, S. 2010. Cover-management factor and soil and water losses from eucalyptus cultivation and Atlantic Forest at the Coastal Plain in the Espírito Santo State, Brazil 11.

Metzger, J. P., Bustamante, M. M. C., Ferreira, J., Fernandes, G. W., Librán-Embid, F., Pillar, V. D., … Overbeck, G. E. 2019. Why Brazil needs its Legal Reserves. Perspectives in Ecology and Conservation. doi:10.1016/j.pecon.2019.07.002

Millennium Ecosystem Assessment, 2005. Millennium Ecosystem Assessment Ecosystems and Human Well-being: Biodiversity SynthesisWorld Resources Institute, Washington, DC.

Morgan, R. P. C. 2005. Soil erosion and conservation. Oxford: Blackwells.

Oliveira, P. T. S., Nearing, M. A., Wendland, E. 2015. Orders of magnitude increase in soil erosion associated with land use change from native to cultivated vegetation in a Brazilian savannah environment. Earth Surface Processes and Landforms, 40, 1524-1532. https://doi.org/10.1002/esp.3738

Pasquatto, M. C. 2016. Influência do uso e ocupação do solo na qualidade da água e no processo erosivo da bacia de captação do rio barro preto, Coronel Vivida (PR).

Phalan B et al., 2011. Minimising the harm to biodiversity of producing more food globally. Food Policy, 36:S62-S71. http://dx.doi.org/10.1016/j.foodpol.2010.11.008

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Sphpritz, L., Fitton, L., Saffouri, R., Blair, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science, 267, 1117-1123. https://doi.org/10.1126/science.267.5201.1117

Roque, F. O., Ochoa-Quintero, J., Ribeiro, D. B., Sugai, L. S. M., Costa-Pereira, R., Lourival, R., Bino G. 2016. Upland habitat loss as a threat to Pantanal wetlands. Conservation Biology, 30(5), 1131-1134. https://doi.org/10.1111/cobi.12713

Rosa, I. M. D., Purves, D., Souza, C., Ewers, R. M. 2013. Predictive modelling of contagious deforestation in the brazilian Amazon, PloS ONE, 8, e7723.

https://doi.org/10.1371/journal.pone.0077231

Rosa, I. M. D. et al. 2017. Multiscale scenarios for nature futures. Nature Ecology & Evolution, 10, 1416–1419. https://doi.org/10.1038/s41559-017-0273-9

Ruthes, J. M., Tomazoni, J. C., Guimarães, E., Gomes, T. C. 2012. Propriedades do Solo da Bacia Hidrográfica do Rio Catorze que Intensificam a Erosão Laminar. Revista Brasileira de Geografia Física, 10.

Sabino, J. & L. P. Andrade. 2003. Uso e Conservação da Ictiofauna no Ecoturismo da Região de Bonito, Mato Grosso do Sul: O Mito da Sustentabilidade Ecológica no Rio Baía Bonita (Aquário Natural de Bonito). Biota Neotropica, 3: 1-9.

Silva, A. M., Alcarde, C., Hitomi, C. 2011. Natural potential for erosion for brazilian territory, In: Godone, D. (Ed.), Soil Erosion Studies. InTech. https://doi.org/10.5772/23163

Smith, P., House, J. I., Bustamente, M., Sobocka, J., Harper, R., Genxing, P., West, P. C., Clark, J. M., Adhya, T., Rumpel, C., Paustian, K., Kuikman, P., Cotrufo, P., Cotrufo, M. F., Elliott, J. A., McDowell, R. I., Griffiths, R. I., Asakawa, S., Bondeau, A., Jain, A. K., Meerdmans, J. & Pugh, T. A. M. 2015. Global change pressures on soils from land use and management. Global Change Biology, 22(3), 1008-1028. https://doi.org/10.1111/gcb.13068

SOBRE – Sociedade Brasileira de Restauração Ecológica. 2019. Nota No 6/2019: A agenda da restauração ecológica no Brasil: Desafios após 150 dias de governo. Retrieved from https://docs.wixstatic.com/ugd/be7ade_7810f33a6aa9480497e9bf5a6e64bcb5.pdf

Sone, J.S., Gesualdo, G.C., Zamboni, P.A., Vieira, N.O., Mattos, T.S., Carvalho, G.A., Rodrigues, D.B., Alves Sobrinho, T., Oliveira, P.T.S. 2019. Water provisioning improvement through payment for ecosystem services. Science of the Total

Environment 655, 1197-1206. 10.1016/j.scitotenv.2018.11.319

SOS-Pantanal, WWF-Brasil, Conservation-International, ECOA, Fundación-AVINA. 2017. Monitoramento das alterações da cobertura vegetal e uso do solo na Bacia do Alto Paraguai Porção Brasileira-Período de análise: 2016 a 2017. Corumbá: Embrapa Pantanal.

Sparovek, G., Reydon, B. P., Guedes Pinto, L. F., Faria, V., de Freitas, F. L. M., Azevedo-Ramos, C., … Ribeiro, V. 2019. Who owns Brazilian lands? Land Use Policy, 87, 104062. doi:10.1016/j.landusepol.2019.104062

Stevens, T. H., Echeverria, J., Glass, R. J., Hager, T., More, T. A. 1991. Measuring the existence value of wildlife: what do CVM estimates really show? Land Economics, 67(4), 390-400. https://doi.org/10.2307/3146546

Stickler, C. M., Coe, M. T., Costa, M. H., Nepstad, N. C., McGrath, D. G., Dias, L. C. P., Rodrigues, H. O., Soares Filho, B. 2013. Dependence of hydropower energy generation on forests in the Amazon Basin at local and regional scales. PNAS. https://doi.org/10.1073/pnas.1215331110

Strassburg, B.B.N., Latawiec, A.E., Barioni, L., Assad, E., Porfirio, V., Valentim, J., 2014. When enough should be enough: improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. Global Environmental Change 28, 84–97. https://doi.org/10.1016/j.gloenvcha.2014.06.001

Telles T. S., Guimarães M. F., & Dechen S. C. F. 2011. The costs of soil erosion. Revista Brasileira de Ciência do Solo, 35.

Tomas et al. 2019. Sustainability agenda for the Pantanal wetland: perspectives for a collaborative interface among science, policy, and decision-making. Tropical Conservation Science

Universidad Stanford. 2013. Ferramenta computacional. Software InVEST® versão 3.7.0, Stanford, CA. Home page. Retrieved from http://naturalcapitalproject.org/download.html.

Uri, N. D. & Lewis, J. A. 1998. The dynamics of soil erosion in US agriculture. Science of Total Environment, 218, 45-58. https://doi.org/10.1016/S0048-9697(98)00198-3

Uri, N. D. 2000. Agriculture and the environment: The problem of soil erosion. Journal of Sustainable Agriculture, 16, 71-94. https://doi.org/10.1300/J064v16n04_07

Uri, N. D. 2001. The environmental implications of soil erosion in the United States. Environmental Monitoring and Assessment, 66, 293-312. https://doi.org/10.1023/A:1006333329653

Wischmeier, W. H., Smith, D.D. 1978. Predicting rainfall erosion losses; a guide to conservation planning. Washington: Agriculture Handbook.

Zeidan, R. 2019. The deforestation bill as a threat to biodiversity. Nature Ecology & Evolution.

Supporting Information for Chapter 2

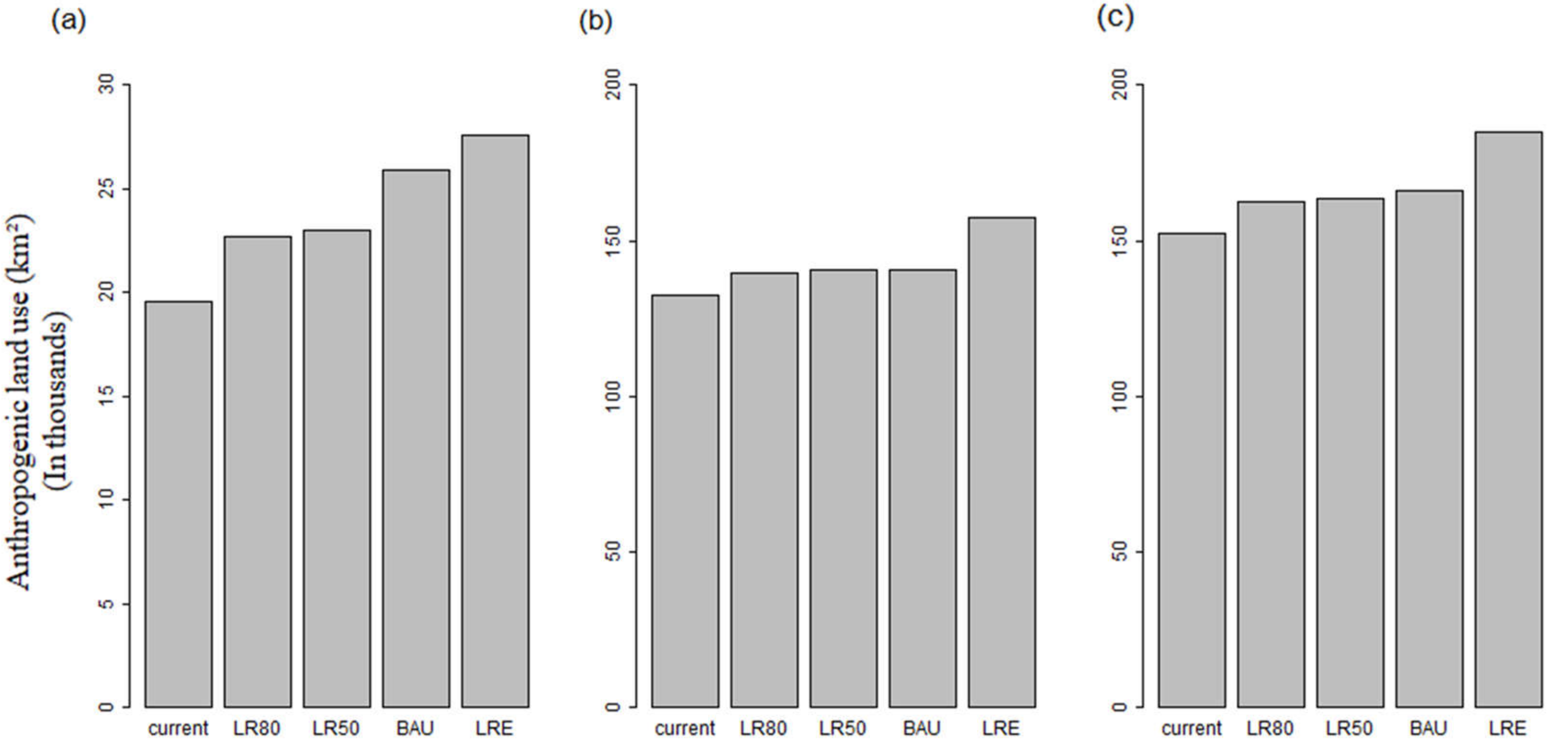

Figure S1. Anthropogenic land use for Lowland (a), Plateau (b), and Upper Paraguay River Basin (c). Legend: (LRE) Legal Reserve extinction as proposed by bill #PL 2,362/2019; (BAU) *Business as usual* considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LR50) 50% Legal Reserve for the Pantanal considering the bill # 9,950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR rates as in the Amazon.

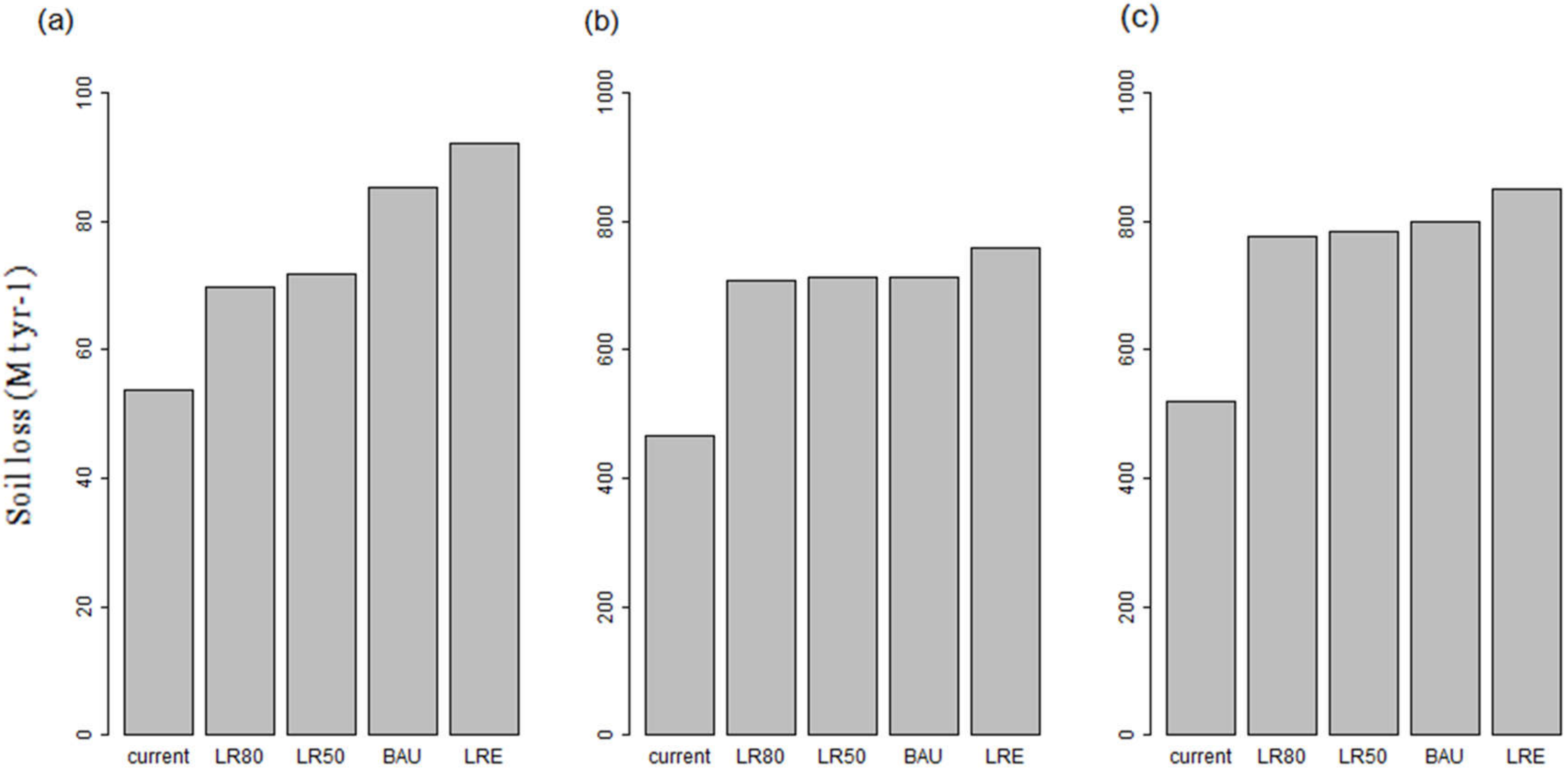

Figure S2. Soil loss for Lowland (a), Plateau (b), and Upper Paraguay River Basin (c). Legend: (LRE) Legal Reserve extinction as proposed by bill #PL 2,362/2019; (BAU) *Business as usual* considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LR50) 50% Legal Reserve for the Pantanal considering the bill # 9,950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR rates as in the Amazon.

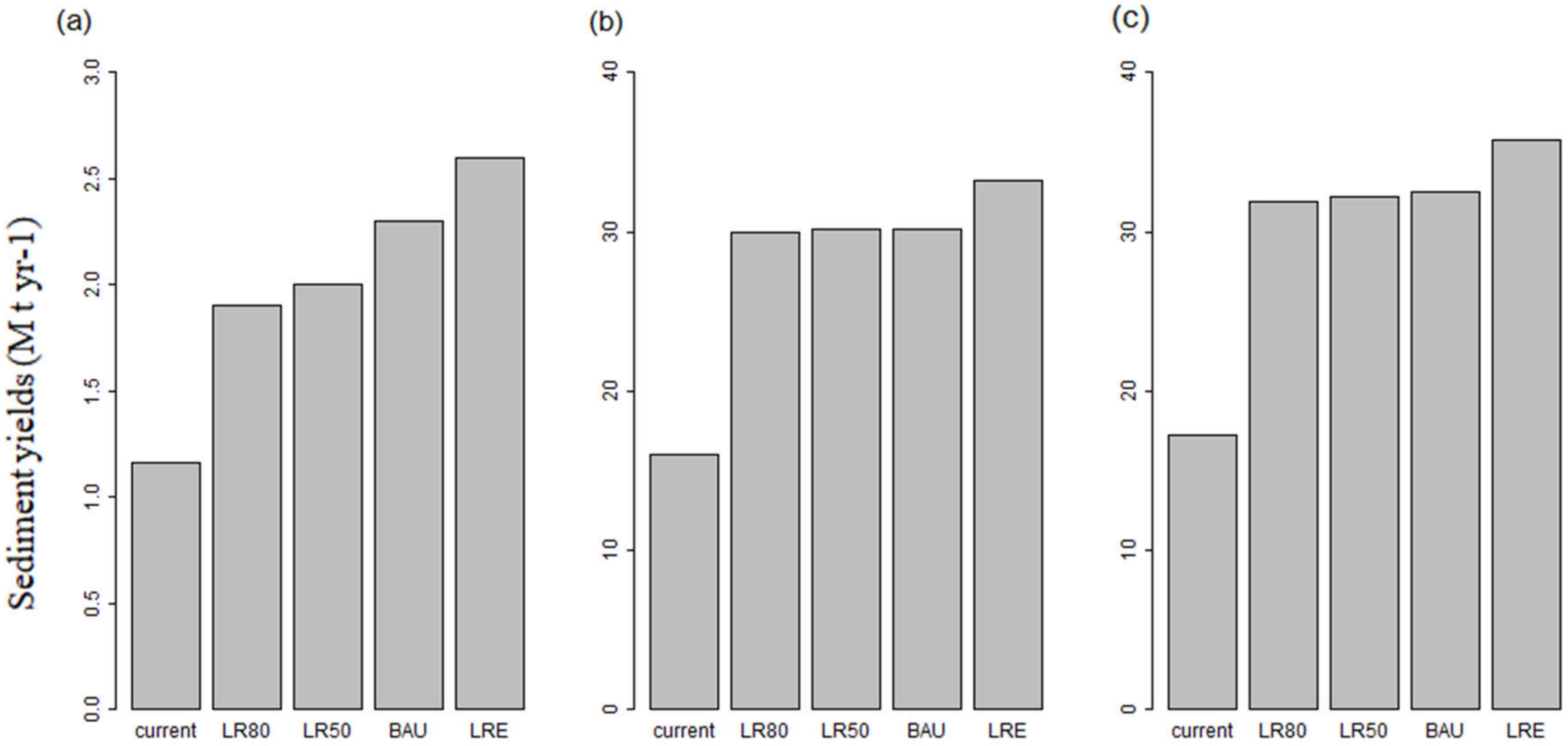

Figure S3. Sediment yield for Lowland (a), Plateau (b), and Upper Paraguay River Basin (c). Legend: (LRE) Legal Reserve extinction as proposed by bill #PL 2,362/2019; (BAU) *Business as usual* considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LR50) 50% Legal Reserve for the Pantanal considering the bill # 9,950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR rates as in the Amazon.

Final considerations

The construction of the separate scenarios for the two areas (plateau and lowland) allowed us to identify the different drivers of vegetation loss between these areas. In the period analyzed, the distance of roads and rivers and altitude only affects the loss of native vegetation in the lowland, while the distance of cities only affects the vegetation loss in the plateau, and only in the period 2010-2012. Among the other drivers analyzed, all were important in explaining vegetation loss on both the lowland and plateau, especially agriculture, which is the main driver of vegetation loss in the Pantanal, and it is a major challenge to reconcile agricultural production with conservation of nature, not only in the Pantanal, but around the world.

If the Native Vegetation Protection Law (NVPL) is met, we expect that by 2050 the lowland will lose over 6,000 km² of native vegetation, while the plateau will lose almost 8,000 km², resulting in a loss of 14,000 km² in the Upper Paraguay River Basin (UPRB). Thus, the lowland will reach 17% of anthropogenic use of its lands and 65% for the plateau. In addition, we identified that vegetation loss in the UPRB forms an Arc, which starts on the plateau and enters the border of the Pantanal lowlands, in transition areas, where land use conversion occurs at an accelerated rate.

The arc of vegetation loss identified in this paper is directly related to the presence of agriculture, which is expanding from the plateau to the lowland and limited by the flood pulse, which prevents the penetration of the Pantanal. The Arc region is rapidly converting land use, and emergency public policies need to be implemented in this area to prevent the loss of essential ecosystem services to the Pantanal due to their location at the plateau interface.

We showed that the extinction of the Legal Reserve would result in the loss of over 32,000 km² of native vegetation in the Pantanal and would increase soil erosion and sediment production, with more than 90% of sediment transported from the plateau to the Pantanal plains. The extinction of the Legal Reserve predicts an 8% increase in soil nutrient replacement expenses. On the other hand, introducing a 50% or 80% Legal Reserve policy in the region would save 1.5% and 10% of nutrient replacement costs compared to the "New Forest Code".

We show here that the Legal Reserve plays a key role not only in conserving native vegetation but also in soil conservation and that maintaining it can help to avoid one of the biggest problems in the Pantanal, soil erosion and river sedimentation, especially in the Taquari region. In addition, maintaining the legal reserve is critical to the development of agriculture in the region, clearly identifying the threshold of its expansion.

Explicit consideration of links between biodiversity and ecosystem services is limited in scale, and therefore impacts of direct drivers on nature are usually modelled independently of their impacts on nature's contributions to people (Rosa et al. 2017). This study involves ecological knowledge, grounding for public policy and conservation. Unlike most studies, it does not focus on how vegetation loss affects biodiversity alone, but rather on hydrological aspects and economic consequences in an integrative way. In addition to contributing to a new look within ecology and conservation studies. I argue that accounting for the role vegetation in the delivery of ecosystem services in future scenarios can only be accomplished by a combination of appropriate scale choice, from predictors to responses.

When indicators that are robust across scales are available, methods that work at multiple spatiotemporal scales can be integrated, such as the ecosystem modelling presented in this study. This approach has grown within Ecology, and can contribute to a better understanding and management of ecosystems from conclusions aimed at applying the results that are produced (Foley et al. 2005, Rosa et al. 2013, Strassburg et al. 2019). Models that couple social and ecological dynamics, mainly due to the development of the landscape ecology discipline, are becoming available, demonstrating that insights from social–ecological feedbacks can be critical for the understanding of ecosystem functioning. This approach allows relating the geographical perspective, which privileges the study of the influence of human modified landscapes and land management, and the ecological approach, which emphasizes the importance of the context, the role of ecological processes, and the importance of these relationships in terms of biodiversity conservation (Hoobs 1994, Metzger 2001, Almeida-Gomes et al. 2016).

Many of social–ecological feedbacks occur across multiple scales through the interaction between the production and consumption of ecosystem services, which is often mediated through institutional and governance linkages (Li 2012). Being able to produce scenarios that relates vegetational loss to agricultural production is essential to help policymakers prepare for potential socioeconomic impacts of environmental changes. The results presented here are fundamental for a synthesis of how we can understand and preserve natural systems, such as the Pantanal, without only contemplating its biodiversity, but also how it affects agricultural production. The results obtained by the proposed scenarios of this study will help to fill the knowledge gaps among the Pantanal and it's contributions to people and human well-being. It will thus rely on broad and interdisciplinary community of scholars, and on the engagement of policymakers, practitioners, and other stakeholders. Only through continued engagement will scenarios be policy-relevant and effectively used by decision-makers at all scales (Rosa et al. 2017).

References

Almeida-Gomes, M., Prevedello, J.A., Scarpa, D.L., Metzger, J.P. 2016. Teaching landscape ecology: the importance of field-oriented, inquiry-based approaches. Landscape Ecology, 31, 929-937.

Foley, J. A., Defries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., … Snyder, P.K. (2005). Global consequences of land use. Science, 309(5734), 570–574. http://www.jstor.org/stable/3842335

Hobbs, R.J. 1994. Landscape ecology and conservation: moving from description to application. Pacific Conservation Biology 1, 170-176.

Li, A. 2012. Modeling human decisions in coupled human and natural systems: review of agent-based models. Ecological Modelling 229, 25-36.

Metzger, J.P. 2001. O que é ecologia de paisagens? Biota Neotropica, 1, 1-2. http://dx.doi.org/10.1590/S1676-06032001000100006

Rosa, I. M. D., Purves, D., Souza, C. & Ewers, R. M. 2013. Predictive modelling of contagious deforestation in the brazilian Amazon, PloS ONE, 8, e7723. https://doi.org/10.1371/journal.pone.0077231

Rosa, I. M. D. et al. 2017. Multiscale scenarios for nature futures. Nature Ecology & Evolution, 10, 1416–1419. https://doi.org/10.1038/s41559-017-0273-9

Strassburg, B. B. N., Beyer, H. L., Crouzeilles, R., Iribarrem, A., Barros, F., de Siqueira, M. F., … Uriarte, M. (2018). Strategic approaches to restoring ecosystems can triple conservation gains and halve costs. Nature Ecology & Evolution, 3(1), 62–70. doi:10.1038/s41559-018-0743-8