Journal of Environmental Management 260 (2020) 110128

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: http://www.elsevier.com/locate/jenvman

Research article

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

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A R T I C L E I N F O

Keywords:
Native vegetation loss
Soil loss
Sediment yield
Erosion
Scenarios
Land use changes

A B S T R A C T

Considering scenarios of future changes in land use have the potential to support policy-makers in drafting environmental laws to reconcile the demands of multiple land uses. The Pantanal, one of the largest wetlands in the world, has been undergoing rapid land use changes, and does not yet have any integrated environmental legislation on Legal Reserve for entire region (LR - minimum percentage of native vegetation required within private properties). The aim of this paper was to generate future vegetation loss scenarios for the Pantanal based on four LR values: (i) BAU: Business as usual, which considers existing laws: Native Vegetation Protection Law and State Decree; (ii) LRE: LR elimination owing to a bill recently proposed; (iii) LR50: which considers the bill proposing 50% of LR for the Pantanal; and (iv) LR80: our proposed levels of 80% of LR for the lowlands and 35% for the plateau (following values in the Amazon). Based on native vegetation loss from each scenario, we estimated the soil loss and sediment yield to rivers. Our results show that LRE would increase native vegetation loss in the Pantanal by as much as 139% when compared to the BAU, whereas increasing LR levels would reduce conversion values by 29% (LR80). Elimination of the LR would increase soil erosion and sediment production by up to 7% and 10%, respectively, compared to BAU. Based on native vegetation loss from each scenario, we estimated the soil loss and sediment yield to rivers with our data showing more than 90% of the sediment transported to the lowland originating from the plateau. The LR80 indicates a reduction in soil nutrient replacement costs of 10% compared to BAU, while in the LR50 these costs decrease by 1.5%, and in the LRE would increase of 8%. Our results show that abolishing current protections would have substantial impacts on avulsion processes, on several economic activities (tourism, fishery, cattle raising, etc.) and negative impacts for biodiversity conservation and would bring losses to agriculture in the Pantanal. Hence, our study brings clearly evidence of LR importance and need to expand it in this sensitive wetland.

1. 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 command as well as control policies are incentivized and supported by the government (Boucher et al., 2013; Stickler et al., 2013).

To ensure the protection of the natural environment in Brazil, several

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https://doi.org/10.1016/j.jenvman.2020.110128
Received 2 October 2019; Received in revised form 2 January 2020; Accepted 11 January 2020
Available online 20 January 2020
0301-4797/

laws have been proposed. The latest and most important is the Native Vegetation Protection Law (NVPL, 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 (i.e., this legal instrument is called Legal Reserve - LR). However, NVPL does not establish a specific LR value for wetlands. In addition, the current Brazilian government has shown signs of weakening environmental laws (e.g. bill 2362/2019, 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).

Global wetlands are responsible for important ecosystem services; thus, they deserve especial attention regarding LCLUC (Davidson et al., 2019). For instance, they can help with the challenge of reconciling biodiversity and agricultural production (Martinelli and Filoso, 2009; Phalan et al., 2019). The Pantanal, one of the largest wetlands in the world and considered a hotspot of ecosystem services (Costanza et al., 1997; Guerreiro et al., 2018), has no specific legislation on LR, despite the Federal Constitution for almost 30 years. At the moment, the Pantanal is designated as a restricted use area (NVPL article 10), allowing its environmentally sustainable use. However, it does not define the concept of restricted use (Tomas et al., 2019), opening up a gap, and leading to risks and missed opportunities for combining conservation with sustainable economic practices. This is because some wetlands such as the Pantanal are dynamic systems, dependent on the flood pulse of the watershed and diversity of landscape patterns with myriad lakes or multi-channelized rivers and "vazantes" (seasonal rivers) that prevent a clear definition of APP (Areas for Permanent Protection like riparian forests) (Bergier et al., 2018, 2019), making it difficult to define the minimum LR. Owing to large diversity of landscapes and flooding

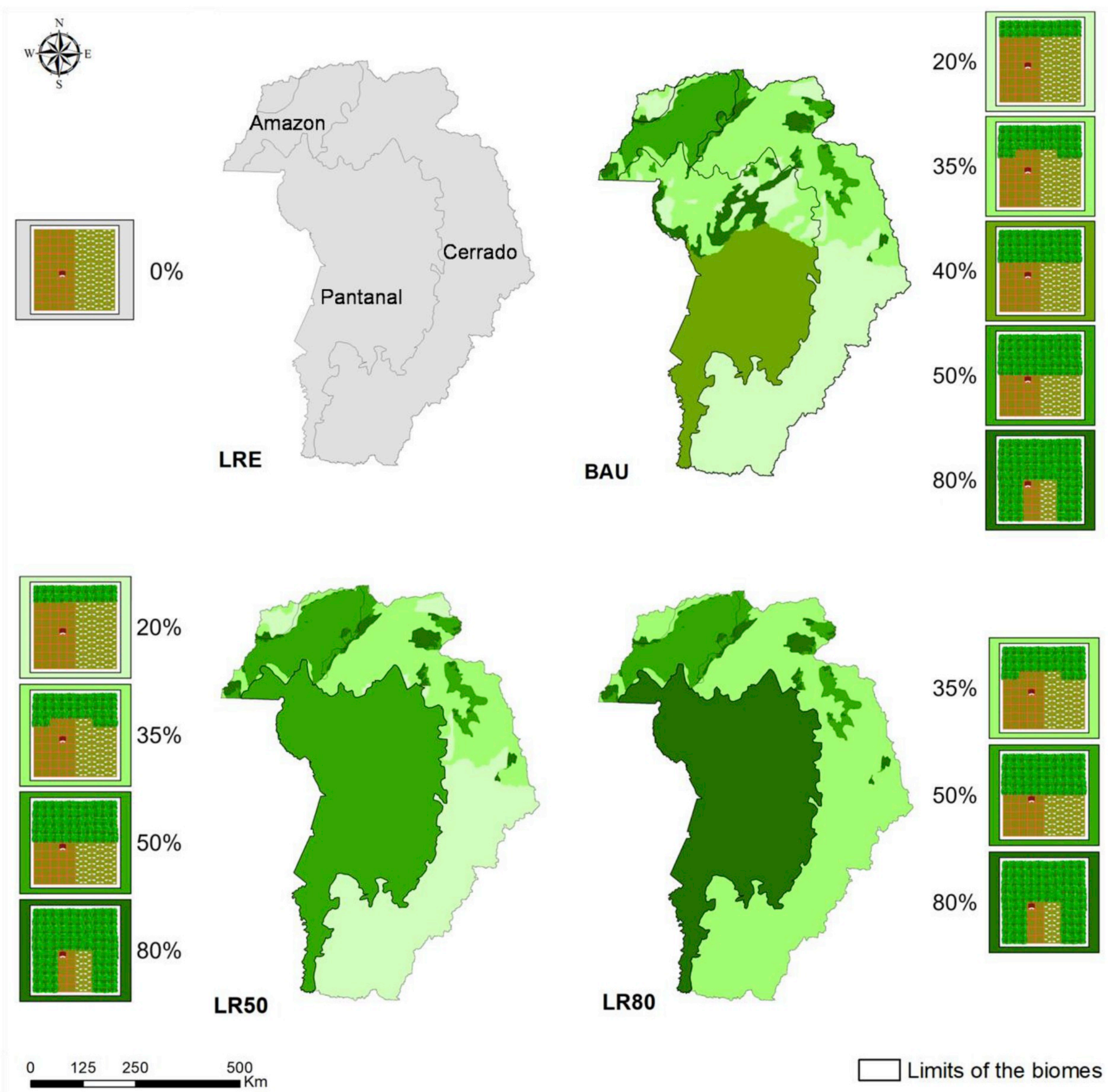

Fig. 1. Definition of scenarios for modeling native vegetation loss, soil loss, and sediment yield at Upper Paraguay River Basin. Legend: (LRE) Legal Reserve elimination as proposed by bill #PL 2362/2019; (BAU) Business as usual, considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LR50) 50% Legal Reserve for the Pantanal considering the bill # 9950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR values as in the Amazon. Projection (WGS 1984 UTM Zone 21S). The colors on the maps correspond to the different values of LR indicated by the outside borders of the boxes. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

regimes (only rain, only fluvial, or both), LR should be carefully looked for each farmland, which is possible because rural properties in the lowland are usually very large (usually ≫5000 ha) (Bergier et al., 2019).

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 drain the lowland originate in the plateau (see Fig. 1 in Guerra et al. 2020), resulting in two areas with great functional and ecological interdependence, but belonging to two different biomes (Assine et al., 2015; 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; Padovani, 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 natural healthy function of the whole biome. Sediment load is responsible to feed and shape megafans in worldwide sedimentary basins (Assine, 2003), but the excess load (Assine et al., 2015) particularly under extreme summer rainfalls due to global climate change that, combined to unsustainable land use, may enhance the value of avulsions in Pantanal rivers (Bergier et al., 2018). 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 and 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. 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 (Borrelli et al., 2017). In this context, it is paramount to estimate whether native vegetation loss may change the functioning of the whole biome according to different policy scenarios. Therefore, the objective of this study is to construct four scenarios of vegetation loss according to implemented law in the UPRB: (i) Business as usual (BAU), (ii) Legal Reserve elimination (LRE), (iii) Legal Reserve of 50% for the Pantanal (LR50); and (iv) suggested values of Legal Reserve of 80% for the Pantanal and 35% for the plateau (LR80) - based on Amazon LR values - 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.

2. Materials and methods

2.1. 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 values set forth in the NVPL and State Decree of Mato Grosso do Sul (#14,273 of 2015); (ii) Legal Reserve elimination (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 #2362/2019 that has been withdrawn on Aug 2019 after public inquiry (https://www25.senado.leg.br/web/atividade/materias/-/materia/136371)); (iii) suggested values of a Legal Reserve of 50% for the Pantanal (LR50), which simulates the LCLUC (considering the bill #9950/2018 that proposes 50% LR values for the Pantanal); and (iv) considering LR values 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 (Fig. 1).

2.2. Modeling native vegetation loss

To model native vegetation loss, we followed the approach proposed by Guerra et al. (2020), who used a spatially explicit model (Rosa et al., 2013) 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, agriculture, 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 Guerra et al. 2020.

2.3. Soil loss estimation

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

$$A = R^{*}K^{*}LS^{*}C^{*}P \tag{1}$$

where: 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 (Fig. A1a; Appendix A) 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 R^2, RMSE, NSE of 0.91, 2350 MJ mm ha^{-1} h^{-1}yr^{-1}, 0.53, respectively.

We obtained the K-factor values (Fig. A1b) of the local studies carried out on different types of Brazilian soils. Table A1 (see Appendix A) shows the classes of soils according to the Brazilian Soil Classification System (SiBCS), soil erodibility values and their respective bibliographic sources. We then assigned these K-factor values to the soil class map developed for UPRB.

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 America altimetry and by-products, then clipped it to the UPRB area and resampled to 250 m using the majority resample, to have the same resolution as the other data.

The LS-factor (Fig. A1d) was computed for each pixel in the DEM, where the L factor is expressed as Desmet and Govers (1996):

$$LS_i = S_i \frac{\left(A_{i-in} + D^2\right)^{m+1} - A_{i-in}^{m+1}}{D^{m+2} \cdot X_i^m \cdot (22.13)^m} \tag{2}$$

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

$$S = 10.8 * Sin\ (q) + 0.03,\ where\ q < 9\% \tag{3}$$

$$S = 10.8 * Sin\ (q) + 0.50,\ where\ q < 9\% \tag{4}$$

$A_{i\text{-}in}$ 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); xi = |Sin αi| - |Cos αi|, where 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).

$$m = 0.2 \, for \, slope \leq 1\% \quad (5)$$

$$m = 0.3 \, for \, 1\% < slope \leq 3.5\% \quad (6)$$

$$m = 0.4 \, for \, 3.5\% < slope \leq 5\% \quad (7)$$

$$m = 0.5 \, for \, 5\% < slope \leq 9\% \quad (8)$$

$$\mathrm{m} = \beta / 1 + \beta \quad (9)$$

$$where \, \beta = \sin /0.0986/(3 \sin 0.8 + 0.56) \, for \, slope > 9\% \quad (10)$$

We used the C-factor values (Fig. A1c) 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 A2; Fig. A1c). Land use classes were taken from MapBiomas 3.0 (http://mapbiomas.org/) with 30 m × 30 m resolution. Accuracy estimates were based on the evaluation of a pixel sample predetermined by statistical sampling techniques. Each pixel from the reference database was evaluated by trained technicians in visual interpretation of Landsat images. Accuracy was assessed using metrics that compare the mapped class with the class evaluated by the technicians in the reference database (Mapbiomas, 2017). 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 into. 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.

2.4. 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 8130 Ottobasins of the 6th order. As a result, the SDR provides the sediment yield to streams and the annual loss of soils in ton. basin^{-1}. After calculating soil loss and sediment yield for each scenario, we compared them based oncurrent and future land use (2017 and 2050).

Error estimates for soil loss and sediment yield were based on the standard deviation of the 100 iterations used in the native vegetation loss model (Please see Methods of Guerra et al. 2020).

2.5. 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 and Pazzianotto, 2004), in each scenario, given by the following equation Eq. (11):

$$CR = \sum_{n-1}^{4} Pn^{*}Qn \quad (11)$$

In which: CR = replacement costs in $/t, Pn = fertilizer price in $/t and Qn = fertilizer quantity in t. Fertilizer prices was based on http://informaecon-fnp.com/insumos/8, considering the current and cash value. 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.

3. Results

3.1. 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 values 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 entire basin, vegetation loss by 2050 can reach 14,005 km^2 in BAU, 32,448 km^2 in LRE (18,443 > than BAU), 11,375 km^2 in LR50 (2630 km^2 < BAU) and 10,005 km^2 in LR80 (3000 km^2 < BAU) (Table 1).

In 2016, the plateau had 61% of anthropogenic land use and the lowland 13%. The accumulated values of vegetation loss show that in 2050 the plateau area can reach 65.0% in BAU and LR50, 72.3% in LRE (7.3% point > BAU), and 64.0% in LR80 (1.0% point < 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% point > BAU), 15.5% by LR50 (1.5% point < BAU) and 15.0% by LR80 (2.0% point < BAU). We map the probabilities of vegetation loss for each scenario (Fig. 2), and in all scenarios the highest probability of loss was found in the plateau and transition regions between plateau and lowland, described as the Arc of vegetation loss in the Pantanal (Guerra et al. 2020).

3.2. 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 (Fig. 3). 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} > BAU), and 241 Mt yr^{-1} for the LR80 (7 Mt yr^{-1}< BAU) (Fig. 3b). 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} > BAU), 18 Mt yr^{-1} in LR50 (13 Mt yr^{-1}< BAU), and 16 Mt yr^{-1} for LR80 (15 Mt yr^{-1}< BAU) (Fig. 3b). 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 (Fig. 4), 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, Fig. 4) to 6–10 t ha-1 yr^{-1} from LRE and BAU to LR50 and LR80 scenarios (in light green, Fig. 4).

The BAU scenario predicts that by 2050 the soil nutrient replacement costs will be USD$15 million. From these, USD $4 million for pasture areas and USD $11 million for UPRB's agricultural areas (Fig. 3d). 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 USD $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

Table 1

Average native vegetation loss (±sd) from 2016 to 2050 in the plateau and lowland in each scenario (km^2). 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 elimination as proposed by bill #PL 2362/2019; (LR50) 50% Legal Reserve for the Pantanal considering bill # 9950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR values as in Amazon.

	BAU	LRE	LR50	LR80
Lowland	6045 (±362)	7932 (±536)	3415 (±197)	3067 (±133)
Plateau	7960 (±1574)	24,516 (±1719)	7960 (±1574)	6938 (±1750)
UPRB	14,005 (±1936)	32,448 (±2255)	11,375 (±1771)	10,005 (±1883)

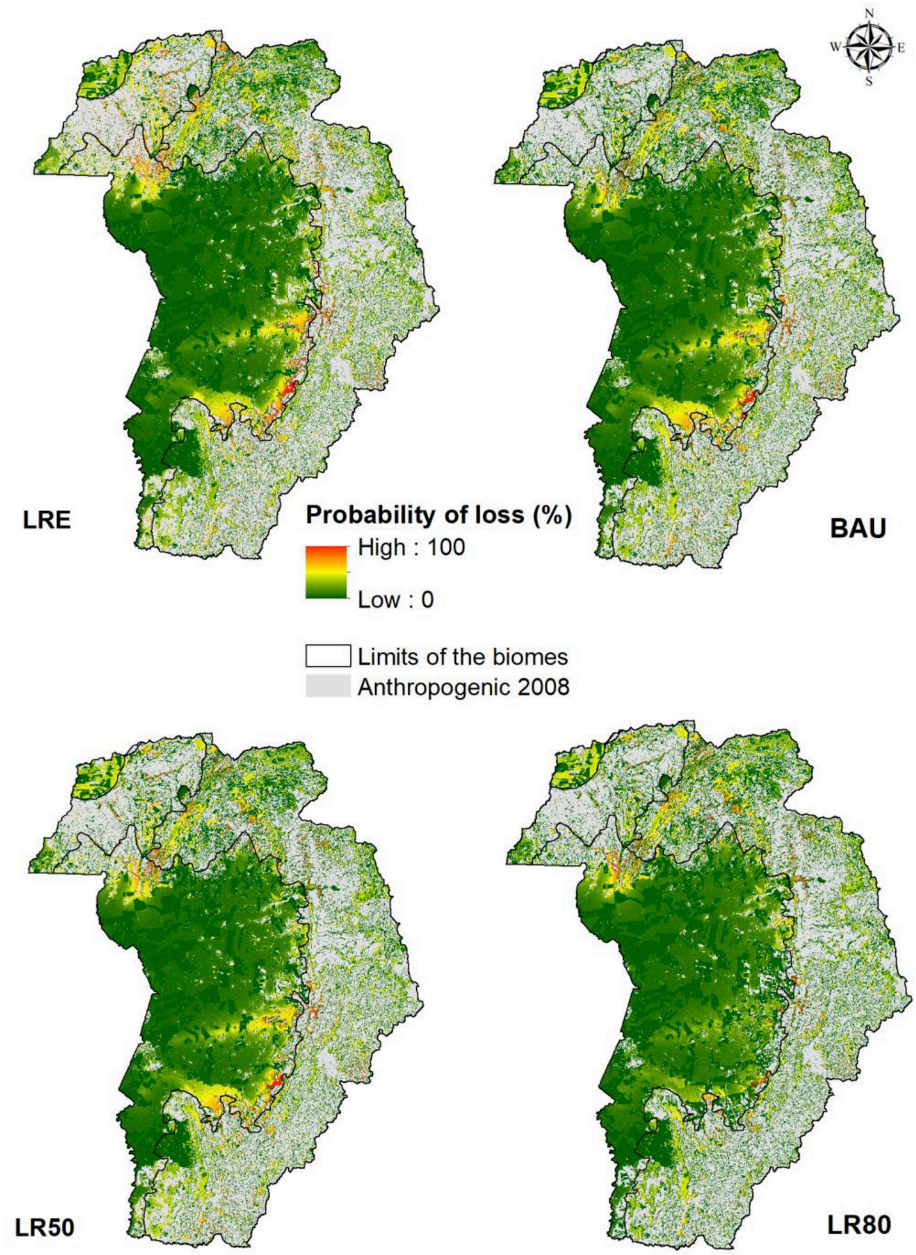

Fig. 2. Probability of native vegetation loss in the Upper Paraguay River Basin by scenario. Legend: (LRE) Legal Reserve elimination as proposed by bill #PL 2362/2019; (BAU) Business as usual, considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LR50) 50% Legal Reserve for the Pantanal considering bill # 9950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR rates as in Amazon.

million) (Fig. 3d).

3.3. *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 (Fig. 3c). 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. More than 90% of the sediment produced in the Pantanal originates on the plateau, which is clear signal of the intricate connection between these two areas (Fig. 4).

4. Discussion

4.1. *Loss of native vegetation*

Our study adds evidences for 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 wetlands such as the Pantanal. Our results show that the elimination of Legal Reserves in properties can increase the value 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.

These values show that increasing Legal Reserve values would decrease vegetation loss in the basin but that the 50% value for the lowlands is not enough to reduce vegetation loss in the region and would decrease very few of the current values. In addition, the LR50 scenario considers the increase in LR values only in the lowlands, while the plateau would maintain its high loss values. Meanwhile, the scenario of

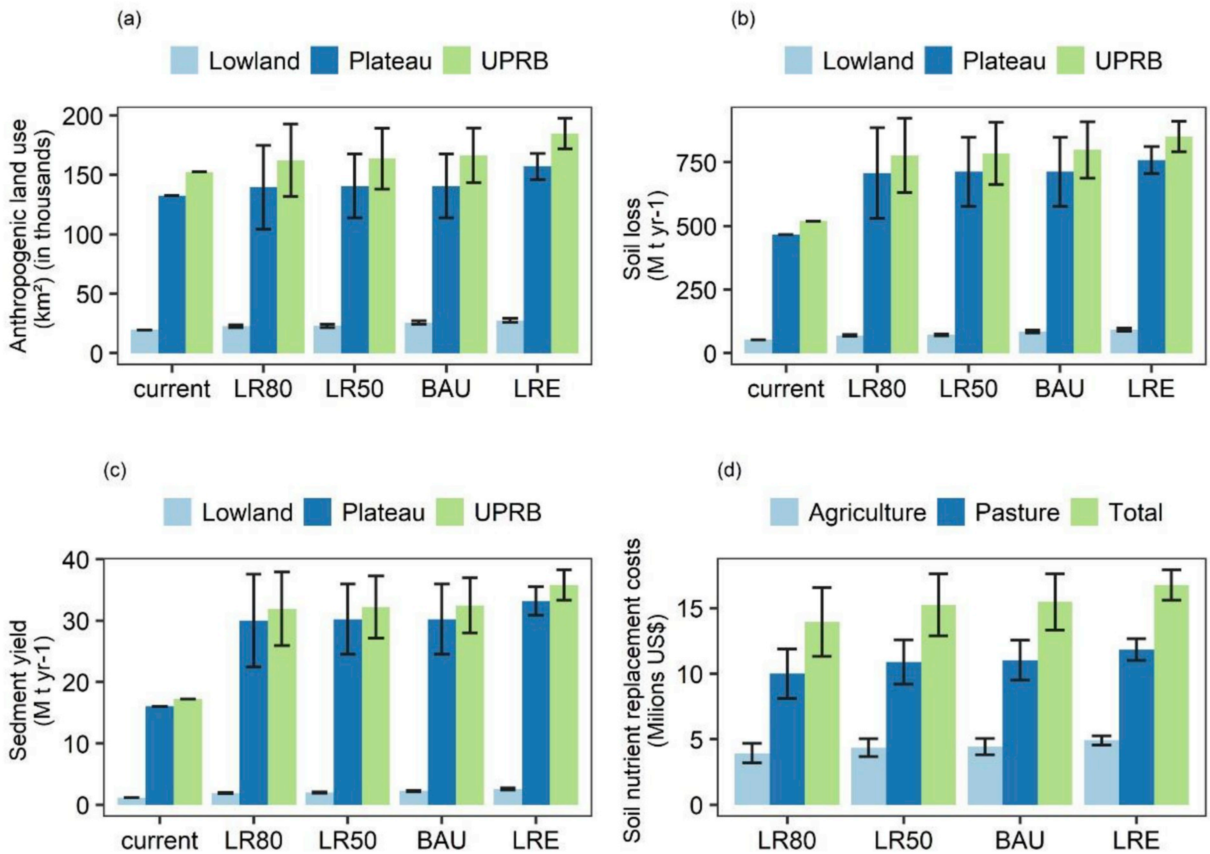

Fig. 3. Anthropogenic land use (a), soil loss (b), sediment yield for (c) for Lowland, Plateau, and Upper Paraguay River Basin and soil nutrient replacement costs in agriculture and pasture areas in the Upper Paraguay River Basin (d). Legend: (LRE) Legal Reserve elimination as proposed by bill #PL 2362/2019; (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 #9950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR values as in the Amazon.

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 elimination 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. Hence, the extinction of the Legal Reserve expected to further increase land conversion values, 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 (SOS Pantanal et al. 2017; Miranda et al., 2018), we consider that it will be converted into a mosaic of pasture and agriculture.

4.2. 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 and 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 and Lombardi Neto, 2008). Our results show that the elimination 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 the nutrient replacement costs by 10% 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 (Strassburg et al., 2014; Metzger et al., 2019), the Legal Reserve elimination would significantly affect agriculture practices given the relationship between the plateau and the lowlands in the UPRB.

The present study 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 and Lewis, 1998; 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,

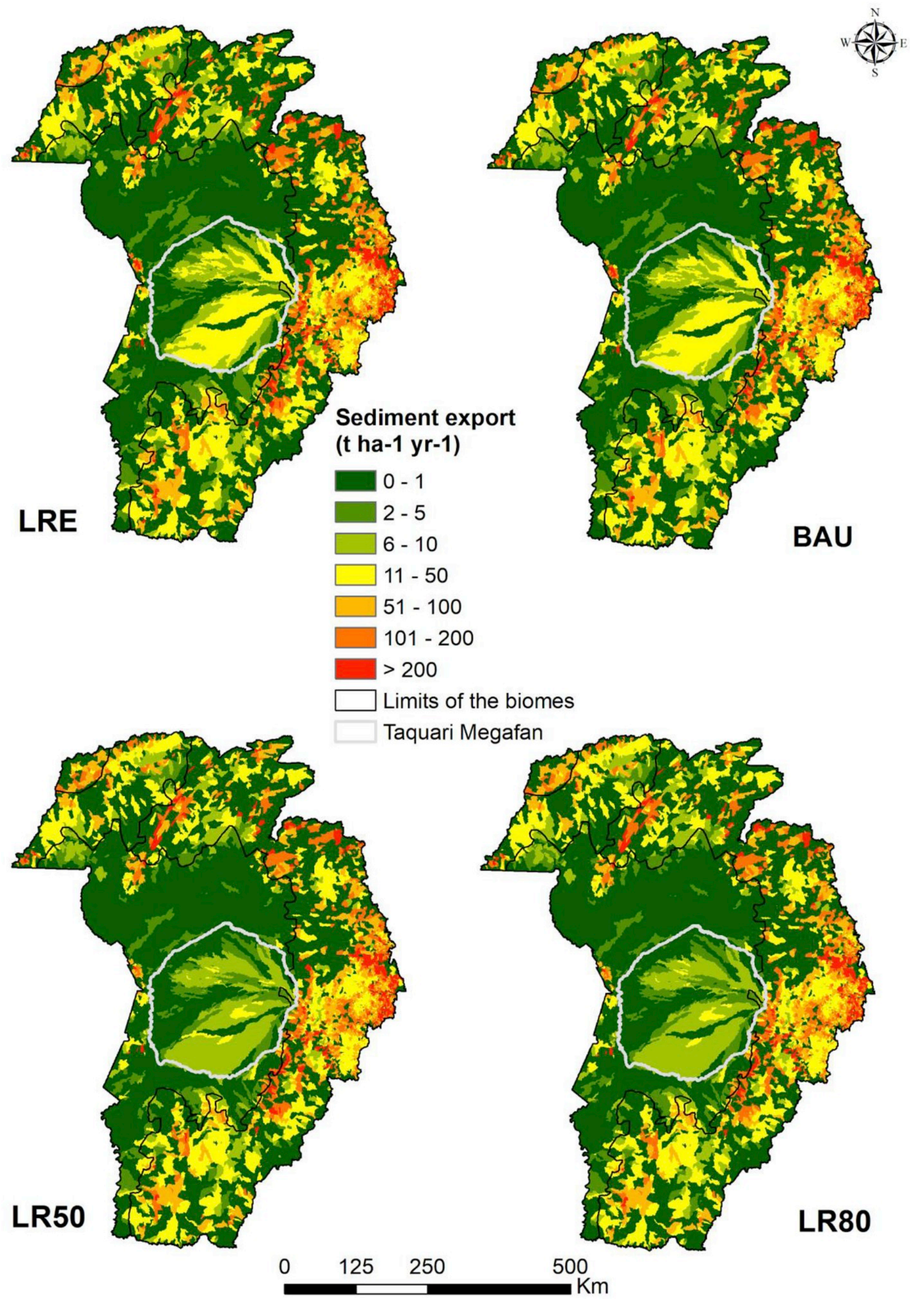

Fig. 4. Projection of sediment yield (tons per hectare per year) in the Upper Paraguay River Basin by each scenario. Legend: (LRE) Legal Reserve elimination as proposed by bill #PL 2362/2019; (BAU) Business as usual, considering current federal and state laws (State Decree of Mato Grosso do Sul # 14,273 of 2015 and Federal Law 12,651 of 2012); (LR50) 50% Legal Reserve for the Pantanal considering bill # 9950/2018; (LR80) Legal Reserve of 80% for the Pantanal and 35% for the plateau following LR rates as in the Amazon. In white we highlight the Taquari Megafan by Mioto et al. (2012).

especially in the Taquari megafan (Adámoli et al., 1985; Assine et al., 2015). The region can be seen in Fig. 4 owing to a great difference with high soil loss in the central part of the map from LRE and BAU to LR50 and LR80 scenarios. In recent years, the river has burst its banks, forming new beds, called "*arrombados*" and leaving thousands of acres of seasonal flooded land (Galdino et al., 2006; Stael et al., 2018). 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. In addition, the summer rain intensity (mm/d) increases over the century and there is a risk of high frequency of avulsion in combination to unsustainable land-use in the plateau/headwaters (Bergier et al., 2018). The avulsion processes recently caused about 150 km of the river to run out of water (Jornal Nacional, 2019). Taquari was recently considered a priority area for restoration in a public call (Art ist, 2nd, of IBAMA/-Portaria # 3447/2018). 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 – Sociedade Brasileira de Restauração Ecológica, 2019). Therefore, we urge 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 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. 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. The Brazilian Pantanal biome is shared by two national states, Mato Grosso (MT) and Mato Grosso do Sul (MS). The recent Bill 9950/2018 is an attempt to improve the LR coverage in the entire Upper Paraguay Basin. On the other hand, while the state of MT have tried to implement the conservation of the Pantanal as trade-off to intensify the agribusiness in the Amazon biome (archived Bill 750/2011), the Agri-Environmental Secretariat (SEMAGRO) of MS state opened for landowners in the plateau the possibility to acquire quotes of LR e.g. in the lowlands (Resolution 673/2019). The underlying idea is the compensation (conservation) of areas of the Pantanal with environmental passives of Atlantic Forest and Cerrado biomes in MS. Despite less restrictive than the Federal Law NPVL, there is the trade-off regarding compensation within or between biomes. If compensation remains within the same biome, Pantanal ranchers may not be attracted e.g. via Environmental Reserve Quotas program (known as CRA) because there are much more assets than demands. Alternatively, the compensation between the Pantanal and other biomes may jeopardize ecosystem services of the latter, whose are particularly important in the plateau-lowland hydro-sedimentation regulation (Galdino et al., 2006; Bergier, 2013). Therefore, the Bill 9950/2018 seems more assertive because environmental services should be regarded as a continuum in space and time, thus hydrographic basin-driven but not biome-driven.

Besides 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 2362/2019 about Legal Reserve elimination 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. The bill has been withdrawn on Aug 2019 after public inquiry. However, in face of land speculation and ongoing environmental legislative changes by federal and state governments (Sparovek et al., 2019) the unstable legal atmosphere in Brazil is particularly worrying. 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.

Here, we show that more important than raising the Legal Reserve rates is to prevent Legal Reserves from being elimination. This elimination would lead to extensive native vegetation loss, and consequent increase in 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 transported into the lowland are produced. Investing in passing environmental protection bills for the Pantanal is critical to ensure its sustainability, ecosystem services and conservation (Tomas et al., 2019).

5. Conclusions

In this study, we discuss how different scenarios of Legal Reserve values in the Pantanal can impact vegetation loss by 2050, and the consequences on soil erosion, sediment yield and cost of soil nutrient replacement for agriculture and pasture.

The elimination of the Legal Reserve would result in the loss of more than 32,000 km^2 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 elimination of the Legal Reserve would lead to 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%, respectively, 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 elimination over vegetation and soil loss, and production of sediments. Besides, we show how the slackening of environmental laws can influence socioeconomic activities in touristic, fishery and agricultural sectors, weakening socioeconomic development of the entire region.

Author contribution statement

Angélica Guerra: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft, Project administration. Paulo Tarso Sanches de Oliveira: Conceptualization, Methodology, Funding Acquisition, Writing - Review & Editing. Fabio de Oliveira Roque: Writing - Original Draft, Writing - Review & Editing. Isabel M. D. Rosa: Methodology, Software, Formal analysis, Writing - Review & Editing. José Manuel Ochoa Quintero: Writing - Review & Editing. Rafael Dettogni Guariento: Writing - Review & Editing. Carina Barbosa Colman: Methodology, Writing - Original Draft. Viviane Dib: Conceptualization, Writing - Review & Editing. Veronica Maioli: Conceptualization, Writing - Review & Editing. Bernardo Strassburg: Conceptualization, Writing - Review & Editing. Letícia Couto Garcia: Conceptualization, Writing - Original Draft, Writing – Review. & Editing.

Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) finance Code 001 and CAPES Print. We would like to thank Fundect (Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado de Mato Grosso do Sul) for granting the scholarship to the first author (59/300.492/2016). The second author was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (grants 441289/2017-7 and 306830/2017-5). FOR received research fellowship from CNPq. We would like to thank WWF Brazil and Cássio Bernardino for their support in continuing this study.

Appendix A

Table A1
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 (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 (2010))
Vertisols	0.0400	Silva et al. (2011)

Table A2
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).

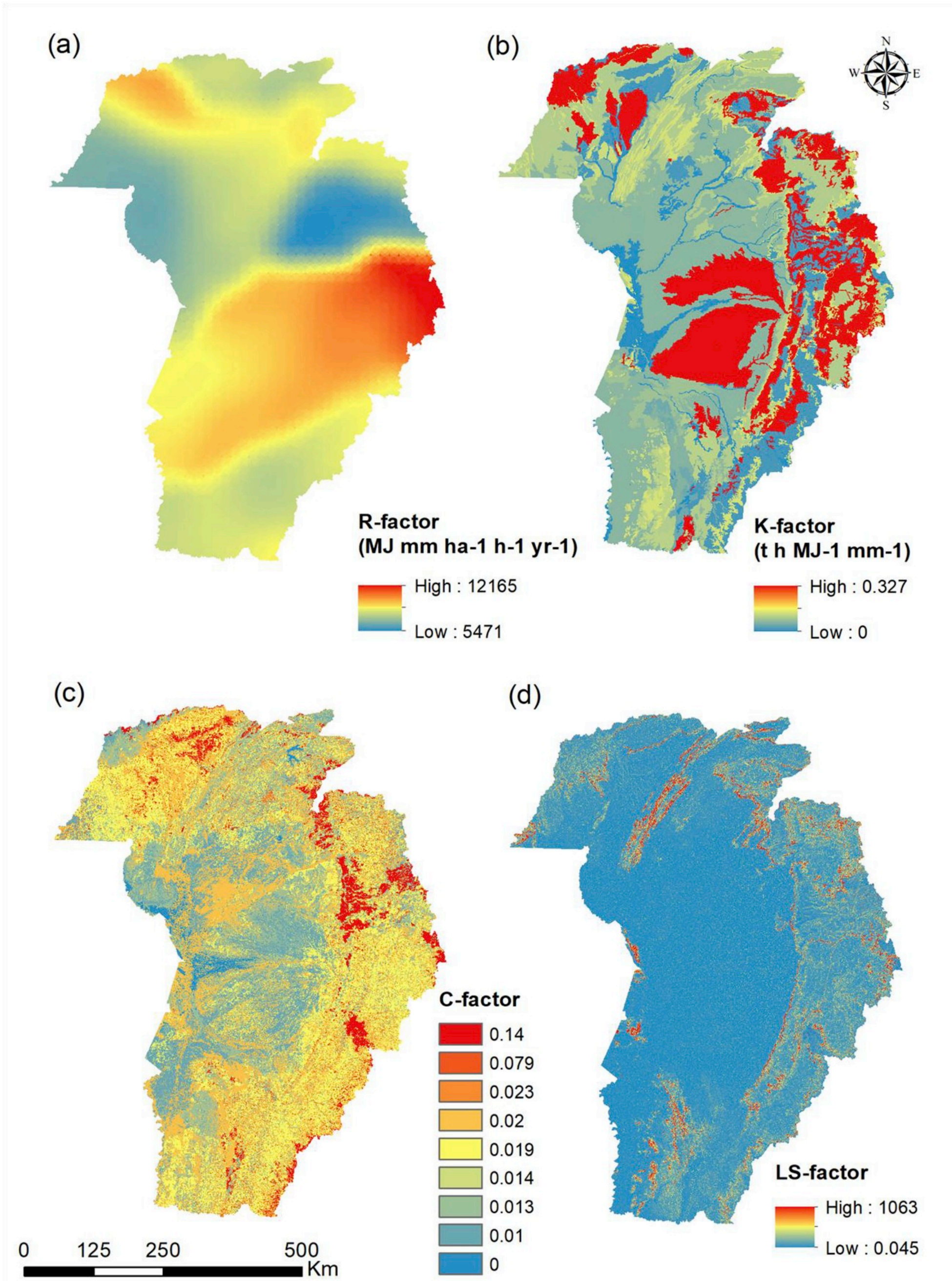

Fig. A1. Maps of (a) R-factor, (b) K-factor, (c) C-factor for land use in the year 2017, and (d) LS-factor (topographic factor) values in the Upper Paraguay River Basin. Projection (WGS 1984 UTM Zone 21S).

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