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Rapid land use conversion in the Cerrado has affected water transparency in a hotspot of ecotourism, Bonito, Brazil

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Abstract

Background: Brazil is the largest exporter of soybeans worldwide. Albeit its economic importance, soybean expansion has led to important land use and land cover changes. In this paper, we evaluate the impact of soybean expansion on ecotourism, using as a case study of the Prata River (Bonito), Brazil; tourist destination where over 30,000 tourists per year came to float in crystal waters.

Methods: We first evaluated land cover and land use change in the region between 2010 and 2020, checking how and where soybean plantations have expanded. Second, based on monthly data of water transparency of the Prata River, Bonito, we created five possible models considering monthly rainfall and three categories of soybean expansion (slow, rapid and medium). The models were tested through generalized linear regression analysis and ranked through AIC and AIC weight.

Results: Our results show that soybean expanded from occupying 4% of the river basin in 2010 to 23% in 2020, expanding mostly over pasture areas (31%) and native vegetation (12.9%). We also showed that while soybean plantation was expanding rapid between 2014 and 2016, it played a significant role in increasing the number of days the water in the Prata River was classified as very turbid.

Conclusion: Our results emphasize the need for soybean expansion planning, considering better management of the soil (non-tilling), common agreements between different stakeholders and the scale up of initiatives that are already in place in the region (e.g. planning of the locations of legal reserves in a way that complement the environmental protection areas (e.g. Águas de Bonito), seting aside of conservation areas ("Área Prioritária Banhados") and payment for ecosystem service schemes) .

Implications for conservation: Our research shows the importance of considering the different impacts soybean may have on the landscape. We present clear paths to reduce possible economic and environmental impacts, and present the importance to scale up innitiatives that are already in place in the region, such as payment for ecosystem services schemes and protection of watersheds.

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ecotourism, soybean expansion, land use, land cover change, sustainability

Introduction

Soybean is the world's largest source of protein for animal feed and the second largest source of vegetable oil (Song et al., 2021), such as glycerine, lecithin, carboxylic acids and their derivatives, lubricants and biodiesel (Zortea et al., 2018). In the last decades, the demand for soybean has increased enormously. For instance, China's soybean imports increased from $2 billion in 2000 to $35 billion in 2014 (Zalles et al., 2019). Latin America stands out as the most important soybean producer. From 2000 to 2019, the area cultivated with soybean went from 26.4 Mha to 55.1 Mha (Song et al., 2021), and Brazil plays the most important role in it, accounting for 37% of the global soybean production (362,947 Mtons per year) (Embrapa, 2021).

Brazil's large soybean production has been constant linked with deforestation. For instance, in 2006, a Greenpeace launched a report linking soybean expansion with Amazon forest deforestation, led, in 2006, to a 'Soy Moratorium': an agreement between producers and buyers that forbids Brazilian institutions to trade soybean linked to the Amazon forest deforestation (Gibbs et al., 2015). However, the report is restricted to the Amazon forest, leaving other ecosystems threated (Soterroni et al., 2019). For instance, in Cerrado, the quantity of soybean increased from 2.702.806 hectares in 1992 to 17.665.895 hectares in 2022, an increase of over 650% (Projeto Mapbiomas, 2022; Souza et al., 2020). Although 80% of soybean expanded over pasture areas, around 16% was over native vegetation (Rausch et al., 2019).

The impact of soybean expansion in Cerrado may be greater than the direct deforestation of native vegetation (Song et al., 2021). Land use and land cover change can create cascade effects on the environment, leading to strong synergic effects (Lambin & Meyfroidt, 2011). For instance, the demand for areas to expand soybeans may increase the price of properties with pasture, which in turn increases deforestation in areas with native forests (Soterroni et al., 2019). Also, pasture areas replaced by soybean may experience an increase in river erosion, since some techniques of soybean plantations (e.g. tilling) have higher soil erosion rates than pasture or native vegetation areas (Merten & Minella, 2013). Given that the Cerrado savannah is considered a hotspot of biodiversity due to its high level of deforestation and rate of endemic species per unit of area (Myers et al., 2000), it is key that we understand all the possible negative impacts of soybean expansion (Song et al., 2021).

In this paper, we use a case study from Bonito region, Brazil centre-west, to discuss the impact of soybean expansion on ecotourism. The region encompasses three municipalities: Bonito, Jardim and Porto Murtinho, and it is globally famous its crystal-clear water lakes, rivers, caves and waterfalls. All three cities are in the state of Mato Grosso do Sul. Bonito is the most important city in terms of ecotourism, hosting most of the hotels and tourist attractions (Figure 1). The city receives yearly over 200,000 tourists (Silva, 2015). Half of the city's workforce is employed by the local ecotourism sector (Silva et al., 2016). Bonito has received several national and international awards, such as 'Best Destination for Responsible Tourism' from World Travel Market and it was elected 16 times as 'The best place to go for ecotourism in Brazil' by the Brazilian magazine 'Revista Viagem e Turismo' (Silva et al., 2016). The most important tourist attraction in the region is the Prata River, which receives over 30,000 tourists per year (Silva, 2015; Silva et al., 2016). Tourists go to the river to float through transparent waters while observing over 80 varieties of fish and, sometimes, large mammals (e.g. tapirs) and snakes (e.g. anacondas). Floating is held in two different rivers: 'Olho d'agua' and 'Prata'.

To guarantee tourists' best experience, the company that manages the floating attraction daily evaluates both rivers' water transparency. If the water is very turbid (less than 5 metres visibility), the river is closed. Olho d'agua River is rarely closed. However, the Prata River has seen an increasing number of days in which tourists' access to the river was closed. In 2018, the Rio da Prata turbidness gained national attention, and it was highlighted in several national media outlets. Local NGOs blamed soybean expansion in the region (Dias, 2000; Oliveira, 2011), whereas soybean producers guaranteed they were expanding over pasture areas and should not be blamed for the turbid waters. In this paper, we evaluate whether soybean expansion has played any role in the number of days the Prata River was closed to tourists, using the results to discuss soybean expansion impacts and possible solutions for it.

Materials and Methods

Data Collection and Analysis

Land use and land cover changes in the Prata River Basin. To evaluate the impact of soybean expansion on the Prata River's water transparency, we first defined the Prata River Basin. The analysis was based on the river watershed and altitude. Ultimately, we wanted to narrow down our analysis to the region where land use and land cover change would directly affect the Prata River's water transparency. Second, we gathered data on all land cover changes within the Prata River Basin between January 2010 and December 2020. We used

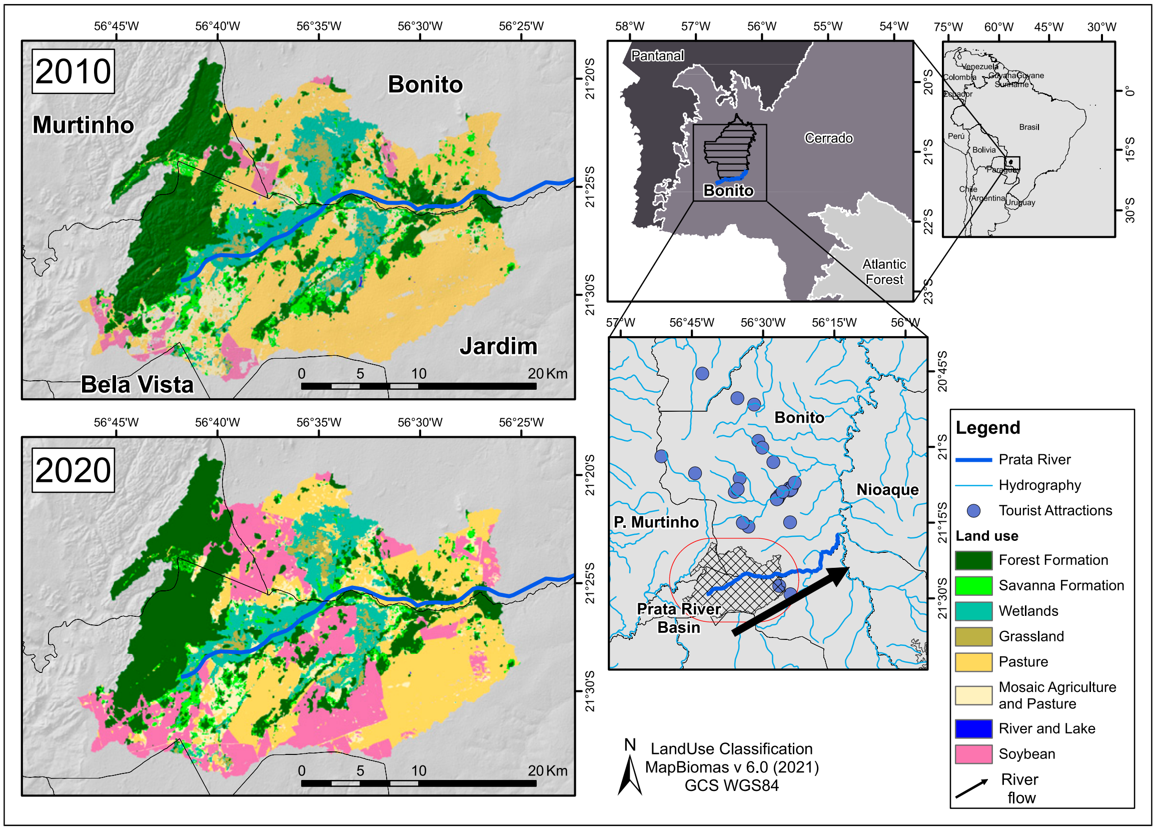

Figure 1. Location of River Prata Basin in the Bonito Region and in Brazil.

data from MapBiomas (collection 6) (Projeto Mapbiomas, 2022). Mapbiomas uses Landsat images of 30 metres of resolution to classify different types of land uses and land covers in Brazil. The data can be accessed freely in their website and can be downloaded as raster. The data is available for each year from 1985 until 2020. For the Cerrado ecosystem, Mapbiomas dataset has an accuracy of 83% (Projeto Mapbiomas, 2022; Souza et al., 2020). In the Prata River basin, Mapbiomas dataset identifies eight types of land uses and land covers: pasture, forest, soybean, savanna, wetland, grassland, water and mosaic pasture/ agriculture (these are areas in which the Mapbiomas could not differentiate between pasture and agriculture). Based on the Mapbiomas information, we evaluated the extent to which each different type of land use and land cover in the Prata River basin has changed between 2010 and 2020. Our diagnosis was conducted using the software Dinamica EGO (Soares-Filho et al., 2013) (Figure 1).

Different levels of Prata River's water transparency. The company that runs the Prata River floating experience classifies the river water transparency every day before they open the attraction. They classify it as transparent (over 10m visibility), turbid (5m to 10m visibility) and very turbid (less than 5m visibility – the river is closed). The company also collects daily data on rainfall. We tabulated all this information from January 2010 to December 2020, creating a table in which we could verify, monthly, the number of days the water was classified as very turbid (river was closed) between January 2010 and December 2020 (Figure 2).

Variation of Prata River's water transparency. We created a set of models we believed it could help us explain the variance in the number of days the Prata River's water was classified as very turbid between January 2010 and December 2020. Each model represented a different combination of two variables: rainfall per month and soybean expansion in the river basin. Rainfall was measured through the quantity of rain in millimetres in each month in the river basin. Soybean expansion was transformed into a categorical variable with three categories: 'medium expansion' referring to a 4-year period, between 2010 and 2013, in which soybean expanded from ~2,700 ha to ~5,200 ha. 'Rapid expansion' in which soybean fast expanded from ~6,400 to ~11,100 ha in a 3-year period, between 2014 and 2016. And, a third category called 'slow expansion' in which the growth has slowed down and soybean expanded from ~12,100 ha to ~14,800 ha in a 4-year period, between 2017 and 2020 (Figure 2). We divided the quantity of soybean in the Prata River basin into three categorical variables because, first, the information on land use

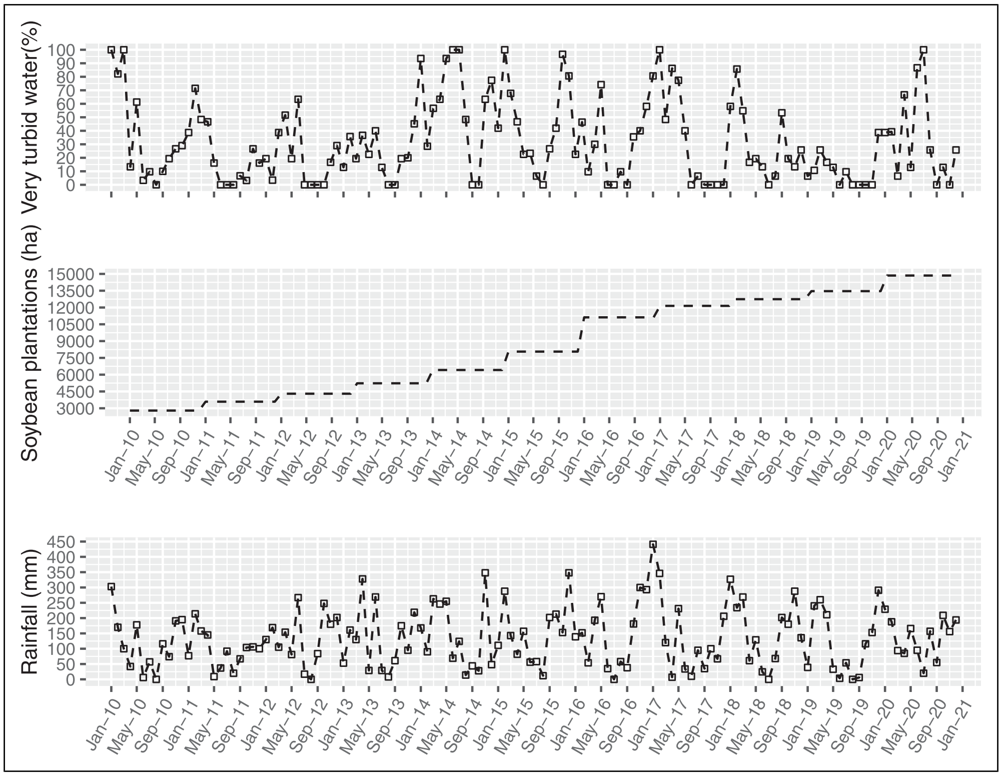

Figure 2. All graphs – left axis: Percentage of days in the month the water was classified as very turbid (the touristic attraction was closed) between January 2010 and December 2020. Right axis, Top graph: Rainfall in each month between January 2010 and December 2020/Middle graph: soybean expansion between January 2010 and December 2020.

and land cover change provided by MapBiomas is available by year. Therefore, we were not able to evaluate monthly the expansion of soybean. Second, we wanted to capture how different levels of soybean expansion in the river basin has affected the water transparency, thus dividing it into categories better capture these changes.

The first model was named ‘Rainfall’. It was created based on the hypothesis that the quantity of rainfall in each month alone explained the variance in number of days in that month the water was classified as very turbid (e.g. more rainfall would lead to more days with very turbid waters and soybean expansion did not play a role in it). The second model named ‘Rainfall + Soybean’ was created based on the hypothesis that the quantity of rainfall in a month and the level of soybean expansion have an additive effect on the number of days in that month the water was classified as very turbid (e.g. more rainfall would lead to more days with very turbid waters, and periods in which the region saw a rapid expansion of soybean would increase the effect of rainfall on water transparency). The third model named ‘Soybean’ was created based on the hypothesis the level of soybean expansion alone in a month explained the number of days in that same month the water was classified as very turbid (e.g. periods with rapid soybean expansion would lead to an increase in the number of days with very turbid waters and an increase in rainfall would play no role in it). The fourth model named ‘Soybean x Rainfall’ was created based on the hypothesis that the quantity of rain in month and the level of soybean expansion had a synergic effect in the number of days in that month the water was classified as very turbid (e.g. rapid expansion of soybean in the region and rainfall would have a synergic effect in the increase in the number of days the water was classified as very turbid). Finally, a fifth model named ‘Null’ was created based on the hypothesis that neither the level of soybean expansion nor rainfall in a month explained the number of days in that same month the water was classified as very turbid (e.g. other possible changes in the landscape or the region, such as number of tourists, was changing the number of days the water was classified as very turbid in the Prata River and neither soybean expansion nor rainfall played a role in it).

All models were tested using a generalized linear models (GLM) analysis based on negative binomial distribution (Lindén & Mäntyniemi, 2011). For each explanation, we calculated the Akaike Information Criterion (AICc) and AIC weight, which aims to rank them in terms of plausibility, in other words, which models, among the ones tested, best explain how well the independent variables explained the dependent variable variance (Burnham et al., 2011). Their selection is based on the GLM analysis and the evaluation of the AICc and AIC weight, which states that differences lower than 2 in the AIC indicate that the explanations are equally plausible (Jørgensen, 2004). Since AIC does not test the model quality, we evaluated standard statistics aspects of the model that was ranked as the most plausible one (Burnham et al., 2011). We tested for significance the variables of the one that was ranked best checking the roles played by the variables tested (estimates) in the variance of the number of days per month the water was classified as very turbid (Table 2). We also tested the residuals of the model in order to understand goodness of fit, we evaluated the relation between the residuals and the predicted values, plotted a normal probability plot and a Scale-location checking whether the residuals followed a normal distribution. All analysis were carried out using R (Crawley, 2007) and the data set and analysis are deposited on-line (Chiarvalloti, 2022).

Results

Land Use Land Cover Changes in the Prata River Basin

Our analysis has shown that soybean plantations went from occupying around 4% of the Prata River Basin in 2010 to occupying over 20% in 2020. Most of the expansion was over pasture areas (31%); yet, we also identified that 12.9% of the expansion was over native vegetation, mostly savanna areas 11.5% (Figure 3).

Different levels of Prata River water's transparency. The quantity of days the company had to close the Prata River attraction to tourists could be divided into the same three soybean expansion periods. First, between 2010 and 2013, on average, the company closed the river for 7.7 days (SD 7.8 days). During this period, the region saw, on average, 119,89 millimetres (SD 16,09 mm) of rain per month and soybean expanded from ~2,700 ha to ~5,200 ha (an increase of 0.48% per year). Between 2014 and 2016, on average, the river attraction was closed for 13.5 days (SD 10.22 days). During this period, on average, the region saw 145,36 millimetres (SD 4,66 mm) of rain per month and soybean expanded from ~6,400 to ~11,100 ha (an increase of 0.57% per year). During the third period, between 2017 and 2020, the company had to close the river, on average, for 8.39 days (SD 9.12 days). During this period, on average, the region saw 142,09 millimetres (SD 12,76 mm) of rain per month and soybean expanded from ~12,100 ha to ~14,800 ha (an increase of 0.40% per year).

Among the five models created aiming to explain the variance in the number of days the company had to close the river to tourists, three stood out as the most plausible ones (Table 1). In all three, rainfall was present (Table 2). In two of them, soybean was present, one showing an additive effect and the other a synergic effect on rainfall (Tables 1 and 2). The null model, which aims to represent all variance not

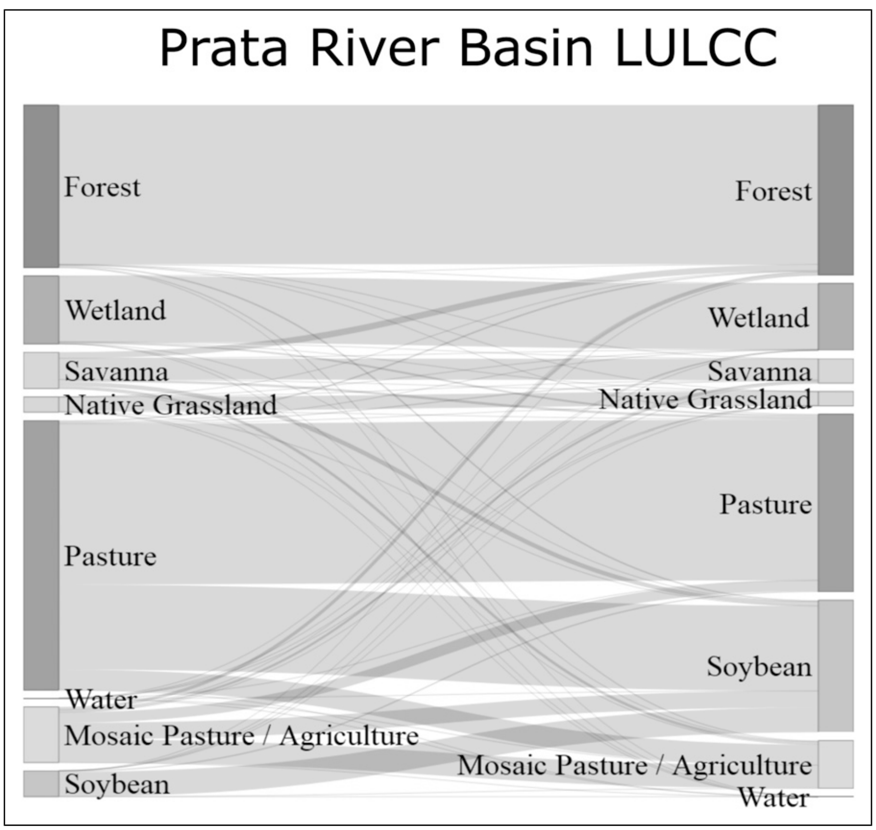

Figure 3. Land use change in Prata river basin between 2010 (right side) and 2020 (left side). Source: MapBiomas.

Table 1. Details of the three best models created to explain the role played by soybean expansion and rainfall in the number of days the company had to close the river attraction due to very turbid water.

Model	AICc	Delta AICc	AICc weight
Model 4 (soybean+rainfall)	851.90	0.00	0.39
Model 2 (rainfall)	852.30	0.40	0.33
Model 5 (soybean*rainfall)	852.76	0.86	0.26
Model 3 (soybean)	871.02	19.13	0.00
Model 1 (null)	871.91	20.01	0.00

explained by the variables analyzed, was not classified among the three most plausible (Table 1). These results indicate that between 2010 and 2020, rainfall was the most important driver of change on the quantity of days the Prata River attraction was closed, and the expansion of soybean plantations on the river basin had a complementary effect.

Looking at the statistical results of the most plausible model (Soybean + rainfall), we can better understand the impact of the soybean expansion on water transparency (Table 2). First, the model showed a good fit for the data, since the relation between the residuals and the predicted values showed to be random and the normal probability plot and a Scale-location showed that the residuals followed a normal distribution (Suplementary Material FS1). In terms of the results, we saw that for each one-unit increase in rainfall, the expected log count of the number of days in a month with very turbid water increases by around 0.005. In other words, if we consider a month with heavy rains, for example, 300 millimetres, during period one (or medium expansion) of soybean expansion, we would expect that the company would need to close the tourist attraction for around 16 days out of 30 days of the month. The model also shows us that the soybean expansion in period two (rapid expansion) increases the expected log count of the number of days with very turbid water to approximately 0.48. Thus, if we see the same quantity of heavy rain (300 millimetres), however, at this time during the rapid soybean expansion period, the number of days the company would need to close the tourist attraction in a month would increase to around 26 days. Finally, the model shows that there is an increase of around 0.06 during the slow soybean expansion period (period three). Thus, 300 millimetres of rainfall in a month during the slow expansion would lead the company to close the tourist attraction for around 17 days. To sum up, the model shows that rapid soybean expansion and heavy rains could create an impossible environment for ecotourism in the region.

Discussion

The Prata River is the main tourist attraction in the region of Bonito. Over 30,000 tourists every year come to the area to float in its transparent waters. The protection of the river is key for both the local environment and the local economy. However, our analysis has shown that rapid soybean expansion in the Prata River Basin between 2014 and 2016 increased the quantity of days the company had to close to river for tourists. Although the quantity of rain played the most important role in it, periods with heavy rain yet slow soybean expansion led to a reduced number of days with very turbid waters. For instance, during the slow soybean expansion period between 2017–2020, the region saw a similar quantity of rain as the rapid soybean expansion period between 2014 and 2016, 145,36 millimetres (SD 4,66) and 142,09 millimetres (SD 12,76), respectively. However, despite similar quantity of rain, rapid expansion increased in 60% the quantity of days the company had to close the river: 13.5 days (SD 10.22 days) and 8.39 days (SD 9.12 days). In other words, rapid expansion and heavy rains could lead the ecotourism activity in the region to collapse.

These results are probably related to the management strategies implemented in soybean plantations in the region. Only 20% of the soybean plantations in the Mato Grosso do Sul state use non-tillage (IBGE, 2017). Tilling requires intensive preparation of the soil, which leads to higher erosion rates than most of other land uses. Considering that most of soybean in the Prata River basin expanded over pasture (36%) and native vegetation (11%), the erosion rate in these areas may have increased from 0.4 t ha^{-1} in pasture areas and 0.1 t ha^{-1} in savanna areas to 6 t ha^{-1} (tilling) (Merten & Minella, 2013), which helps explaining why we saw an increase in the number of days with very turbid waters during rapid expansion.

In this paper we uncovered an important link between soybean expansion, nature conservation and ecotourism. In the Prata River Basin, as similarly to other areas, soybean expanded mostly over pasture land (Rausch et al., 2019; Song et al., 2021; Zalles et al., 2019). In most regions, this land use change would not directly affect the local economy. In regions where the main economic activity is agriculture or cattle ranching, higher levels of erosion may take few years to start to cause economic impacts (Merten & Minella, 2013). Nonetheless, in the case of the Prata River basin, this land use change has affected ecotourism directly, since the economic sustainability of the company that owns the area is underpinned by the rivers' high level of water transparency. It is important to note our analysis was focused on the Prata River; and, Bonito region has another 20 ecotourism destinations which also have their economic activities based on the presence of transparent waters (Oliveira, 2011; Silva et al., 2016). It is a business model that generates over US$ 96 million per year and employs half of Bonito's workforce (Oliveira, 2011).

Bonito case study nicely illustrates an important threat to nature-based tourism globally. Nature-based tourism represents an important business model for both local economies and nature conservation. For example, wildlife tourism in Africa attracts ~70 million visitors per year, representing ~8.5% of the continent's GDP (US$10–50 billion) (Lindsey et al., 2020). In Costa Rica, 2.6 million ecotourists visit the country's rainforest every year, generating US$2.8 billion or

Table 2. Models created to test the role played by each period of soybean expansion in the Prata River Basin and rainfall on the number of days the company had to close the river attraction due to very turbid waters.

Models	Variables	Estimate	*p*-Value
Model 4 (soybean+rainfall)	Rainfall	0.0048388	8.61e-07*
	Soybean 1	1.3229702	5.20e-11*
	Soybean 2	0.4828754	0.0466*
	Soybean 3	0.0622764	0.7840
Model 2 (rainfall)	Rainfall	0.0049943	5.68e-07*
Model 5 (soybean*rainfall)	Rainfall	0.008287	1.37e-05*
	Soybean 1	0.868048	0.00276*
	Soybean 2	0.957403	0.02510*
	Soybean 3	0.717628	0.06687
	Soybean 1* Rainfall	0.868048	0.00276*
	Soybean 2* Rainfall	−0.003581	0.16533
	Soybean 3* Rainfall	−0.004925	0.04125*

12.5% of the country's GDP (Valverde Sanchez, 2018). Globally ecotourism may generate US$1 trillion per year, with some arguing that ecotourism makes up more than 25% of the global travel market (Cordell & Bowker, 2007). However, despite their financial successes, many of these areas are threated. For instance, Kenyan National Parks have seen a reduction of a 72–88% in large mammals population due to poaching and land use land cover change (Ogutu et al., 2016), Similarly, in the Pantanal wetland, Brazil, although jaguar tourism generates over US$6, 8 million per year (Tortato et al., 2017), in 2019, mostly human-induced fires burned 30% of the ecosystem, affecting mainly habitats that are suitable for jaguars (Libonati et al., 2020; Tortato et al., 2021).

To protect a business model that promotes both biodiversity conservation and economic development is key that we implement initiatives take into account different aspects of the landscape. The first important initiative is to avoid deforesting new areas to open space for soybean, a call that has been made several times (Soterroni et al., 2019). In our analysis, we showed that almost 13% of the soybean expansion was over native vegetation (Myers et al., 2000). Given the uncountable impacts of replacing native vegetation with soybean plantations, it is key that strict measures are taken to avoid further deforestations. In the Amazon, the soybean moratorium has brought a relatively success and only around 2% of the soybean currently planted in the Amazon region is related to forest loss (ABIOVE, 2021). It is also important to better define different strategies for different regions of the landscape. In the state of Mato Grosso do Sul, soybean plantations expanded 1.7 times between 2010 and 2020, which is less than the expansion seen in Bonito municipality (4.29 times, and in the Prata River Basin 5.48) (Projeto Mapbiomas, 2022; Novaes et al., 2017). Therefore, despite Bonito and Prata River's transparent waters uniqueness, there has been a strong focus of soybean producers on the region (Souza et al., 2020). It is key that local policy makers drive soybean expansion towards areas where soybean would cause less environmental and economic impacts (Nepstad et al., 2019; Valverde Sanchez, 2018). It is also key that policy makers and practitioners scale up prioritization strategies at the local level that are already in place. All properties in Brazil are required to set aside a legal reserve of 20% in the case of Cerrado and an environmental protection area around water bodies (law number 12651, from May 2012). Although landowners are free to decide the location of their legal reserve, this can be defined collectively. A group of policy-makers, NGOs, ranchers and public prosuecutors is already pushing this agenda forward through the innitiative "Projeto Águas de Bonito", which aims to protect and restore riverine vegetation in the region. There is also a programme focused on paying ranchers for ecosystem services and another one focusing in seting aside conservation areas around watersheds. All these initiatives help to create ecological corridors and larger environmental protection areas around water bodies, protecting the region from possible environment and economic impacts of further land use and land cover changes. By scaling up these initiatives to other areas and regions of Bonito, local stakeholders guarantee that agriculture, nature protection and economic development walk hand in hand in a unique place of the country.

Conclusion

Our results emphasize the importance of land use planning in the fragile Karst of the Bodoquena mountains, where Bonito is located. This includes soil conservation and terracing to avoid runoff during heavy rains, improvements on rural dirt roads to avoid siltation of rivers due to runoff, improvements of native riverine vegetation protection rules, better planning of legal reserves to increase the protective strips along rivers, streams, and wetlands, prevention of artificial draining of wetlands, and restoration of wetlands subjected to artificial drainage. Some of these measures have been already implemented in the region (e.g. Projeto Águas de Bonito) and scaling them up is critical, to guarantee Bonito's ecoturim, local development and environmental protection.

Implications for Conservation

Our paper brings three important conservation implications. First, it is key that soybean does not expand over native vegetations . Second, it is key that soybean producers that are still using tilling management practices, replace it with with non-tilling, which can reduce soil erosion from 6.0 t ha^{-1} to 0.1 t ha^{-1} (Merten & Minella, 2013). Finally, it is fundamental to scale up the initiatives that are already in place in Bonito region. The tourist attractions in the region are considered one of most important destinations in Brazil, and scaling up the current initiatiaves focused on land planning is key to keep the region as an example for other areas in Brazil and around the planet as a sustainable ecotourism hotspot.

Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

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