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# 10-Years Land Use Changes Decrease Landscape Integrity in a Brazilian Hydrographic Basin

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## Abstract

Changes in land use associated with the suppression of native vegetation can greatly alter the landscape configuration, affecting biodiversity and environmental services availability. This study analyzes how changes in land use affect landscape patterns of vegetation remnant over a 10 year period. We quantified spatial landscape patterns throughout a hydrographic basin for the years 2002, 2008, 2010 and 2012, using nine landscape metrics. An indicator of integrity was used to details the transformation processes occurring in the basin that could be used to monitor the impact of landscape changes and its spatial patterning. Results showed that over this decade, extension of farming activities reduced the cover of native vegetation by 4.4%, with grassy-woody savanna, wooded savanna and forested savanna impacted especially strongly. Suppression of vegetation across this period reduced the size of fragments and their connectivity. The landscape fragmentation indicator indicated that the fragmentation pattern varied spatially, with the upland areas along river headwaters, being most fragmented. Areas of floodplains vegetation, belonged to the Pantanal Wetland, although in better integrity states, are the most threatened by current pressures of land use change. An intense recovery program for headwaters and aquifer recharge areas, as well as riparian forests, is recommended to avoid the future depletion of water production. Besides, we also recommend the maintenance and recovering of the connectivity of the current remaining patches of natural vegetation corridors and elaboration of specific laws that incoporate the consolidated scientific knowladge about wetland ecosystem functioning, like the Pantanal.

**Keywords**

Connectivity, GIS, Metrics, Catchment Area, Fragmentation, Remnant Vegetation

## 1. Introduction

Changes in land use associated with the suppression of native vegetation are of great concern to human populations because of its consequences for biodiversity loss, climate change, carbon sequestration, food provision, and other ecosystem services, such as maintaining the quality and availability water [1]. Recently, the speed at which these changes occurred, associated with technological developments and economic interests, is leading the world to an unsustainable trajectory [2].

Among the biggest changes associated with the removal of vegetation cover is the fragmentation of native vegetation [3] [4]. The fragmentation process is represented by the increase in the number of fragments or remnant patches in a landscape [5]. Furthemore, the loss of native vegetation can affect the spatial structure of the landscape in various ways. Loss of the same amount of remaining area, for example, can result in an increased number of fragments, as well as in no changes in the landscape configuration. One large remaining contiguous patch can become numerous small and isolated fragments [6]. The direction of these changes is not easy to predict because it depends on several factors that act integrally, including the biophysical heterogeneity of the environment and the socio-economic and political influences on the human activities transforming the landscape [7] [8].

The impacts of habitat fragmentation on biodiversity conservation and management have been widely discussed [3] [6] [9] [10]. Fragmentation can result in the formation of landscapes with little diversity in terms of habitat and species [3]. A new landscape mosaic composed of remnants of native vegetation, surrounded by disturbed areas, impacts and changes the dispersal and movement of species across that landscape. Endemic species are more likely to be impacted, because of their smaller capacity for dispersion and their habitat specialization [9]. Fragmentation reduces the connectivity of the landscape and, therefore, the ability of species to travel between habitat patches, resulting in changes in species distribution patterns [11] [12], and an increase in the possibility of local extinctions [13]. Species extinction can have a strong impact on the integrity of ecosystems, since component species regulate the availability of environmental resources, control population densities through inter-specific interactions, and are integrated into a range of environmental services, such as water cycling, soil formation, nutrient and energy fixation, and climate maintenance [14].

The success of sustainable conservation and use strategies in ecosystems depends on adequate information across a variety of formats, including documents, images and maps that together indicate the direction and speed of change. Together, these can be used to plan land use management that can be conducted to ensure the availability of ecosytem services over the long term. Geographic information systems and analysis of spatial patterns provide an analytical approach to investigate change in spatio-termporal patterns of land use and cover, assisting in the detection of changes in such factors and determining the distribution and extent of modified areas [15] [16] [17]. A large number of indices have been developed to quantify the spatial heterogeneity of landscape in categorized maps [7] [18] [19]. These indices fall into two general types, which together affect how ecological processes are recorded and how this translates into perceived changes in landscape patterns. They are: 1) indices which evaluate the composition of a map without reference to such spatial attributes such as shape and size of a fragment; and 2) indices which assess the spatial configuration of system properties, and require spatial information, such as levels of patch isolation and connectivity, for their calculation [7].

The use of landscape indices or metrics to characterize changes in ecosystem services, landscape functions and integrity caused by logging, agriculture and urbanization has been increasing at the last decade [2]. These are key attributes indicating the integrity of a system, related to the degree of influence of human activities and the system capability to maintain natural communities [20]. In large scales, monitoring rates of vegetation suppression have revealed the speed in which remaining natural habitats are loss. This information indicates the clearing extent across bioregions, but lack to provide an indication of the consequences of habitat loss to landscape configuration, in special, connectivity, which may play deep effects on conservation of biodiversity [9] [21]. Detecting and monitoring the impact of human activities on landscape status may be done by integrating a set of complementary landscape indices, rather than describing them separately [22].

The aim of the study was to analyze the spatial and temporal changes in land use and cover and fragmentation of remaining native vegetation from 2002 to 2012 in a Brazilian hydrographic basin and to provide an indicator of landscape integrity (ILI) that can be used to monitor the landscape status over time and space. In this study we ask: 1) what was the suppression rate of native vegetation over a 10-yearperiod; 2) what were the main changes in the landscapes pattern over 10 years, and 3) how these changes affected landscape integrity.

## 2. Study Area

This study was conducted in the hydrographic basin of the Miranda-Aquidauana Rivers (hereafter called Miranda basin), located in the midwest region of the Mato Grosso do Sul, Brazil (**Figure 1**). The basin has a drainage area of 43,787 km$^2$. The study site lies between the coordinates 19˚20'21.5"S and 22˚1"28.4'S and 57˚27'56.1"W, 54˚25"40.3'W, an area of some 44,740.50 km$^2$. The Miranda basin is part of the Upper Paraguay River Basin and according with the Brazilian Institute of Geography and Statistic (IBGE) it is 83% within the Cerrado (Brazilian savanna) and 17% in the Pantanal Biome. It is bordered to the north by the

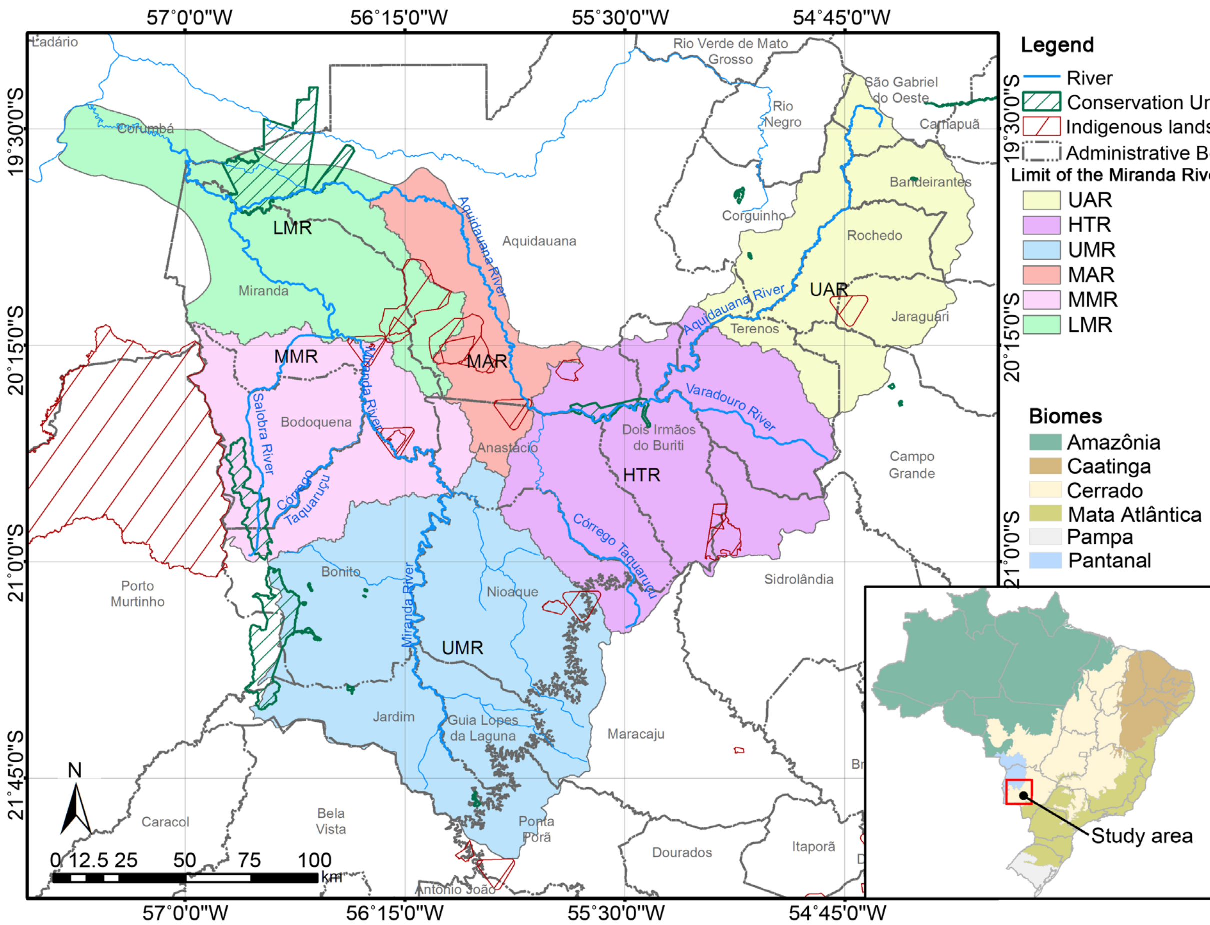


**Figure 1.** Location and subdivisions of the Miranda River hydrographic Basin.

River Negro watershed, to the west by the Nabileque River watershed, and to the south and southeast by the ApaRiver watershed.

A short stretch to the northwest has borders with the Taquari River watershed. The principal rivers that contribute to the drainage basin are the Aquidauana, Miranda, Salobra, Formoso, Nioaque and Santo Antonio [23].

The basin is located within the Tropical Zone, with influence of two climates: tropical climate with a dry season (Aw), also known as savanna climate, and semi-humid tropical climate or tropical monsoon (Am), both characterized by a marked alternation of rainy and dry seasons. Temperature ranges between 16˚C and 28˚C, with an annual average of 22˚C. The annual rainfall varies from about 1650 mm in the headwaters to 1000 mm in the western Pantanal floodplains. The annual evaporation is about 1140 mm [23].

There are contrasting relief forms in the basin, with plateaus and hilly terrains in altitudes up to 500 meters (e.g., the Serra do Maracajú and Bodoquena), and elevations lower than 200 min the Pantanal Wetland. The presence of basaltic rocks in parts of the plateau, especially in the Serra do Maracaju and Bodoquena is associated with local presence of fertile soils, such as purple eutrophic Oxisol, and structured eutrophic *terra roxa*. Calcareous-dolomitic rocks are also present in Serra da Bodoquena, what makes this region more vulnerable to deforestation. In the valleys of Aquidauana and Miranda rivers, there are dark red alic Latosols and Regosols, respectively. Typic Natrustalf predominates in the pre-Pan- tanal lowlands [23].

The vegetation belongs to the Cerrado phytogeographic domain. Most of the upland areas are covered with deciduous and semi-deciduous Cerrado. Forest formations under fluvial influence (e.g. cambarazal, carandazal) followed by grassy-woody savanna dominate in the Pantanal [24] [25]. Because of its high biodiversity and elevated threat level, the Cerrado biome is a hotspot for biodiversity conservation, having a high risk of being increasingly reduced to smaller vegetation fragments [26] [27]. The agricultural expansion is favoured by the disconect between environmental legislation and land policy and is the principal responsible for deforastation of its native vegetation formations [27], modifying the structure, composition and functioning of Cerrado ecosystems [28].

The basin includes seven sustainable use protected areas, three fully-protected conservation units (e.g. Serra da Bodoquena National Park) and eight areas of indigenous land, which together amount to approximately 4% of the total area (**Figure 1**). Because it is an area of high ecological value, 51% of the basin was decreed as a conservation priority area by the Ministry of the Environment through the Decree number 5092 of 21 May 2004, and through the Ordinance number 126 of 27 May 2004.

The 23 municipalities in the basin have different socioeconomic profiles [23]. On the plateaus predominates agriculture, while on the lowlands, e.g. the Pantanal, livestock are dominant. The main activities threatening conservation of the region's fauna and flora are mining, and the extraction of charcoal and timber, which have increased very quickly in the state. These activities are closely linked to cattle-raising, because the vegetation removal that starts the process is the result of partnerships between cattle ranchers, interested in increasing their area under exotic pasturage, and the owners of charcoal and lumber concerns, who require wood to their enterprises [29]. Irrigated rice cultivation, soyabean/crop consortium and planted eucalyptus forest are also current management activities that threats ecosystem integrity.

## 3. Methodology

### 3.1. Watershed Delimitation

Watersheds are appropriate spatial units for the evaluation of impacts caused by human activity, especially when these are related to land use and may pose risks to maintainence of sutainable water resource availability in quality and quantity [30].

In order to detail the process of landscape change in the Miranda basin and relate this to the regional hydrological and socioeconomic characteristics, we subdivided the basin in 6 watersheds, using the fluvial level gauges for drainage watershed limitation in the river monitoring belonged to the National Water Agency (ANA), as implemented in the Finep/CT-Hidro Project entitled "Development of Watershed Quality Indicators for the Tietê/Jacaré (state of São Paulo) and Miranda (state of Mato Grosso do Sul) rivers for Water Quality Maintenance".

Headwaters areas were represented by 3 watersheds: the Upper Aquidauana-River (UAR); the Headwaters of Varadouro-Taquaruçu River (HTR); and the Upper Miranda River (UMR). Mid basin units were represented by the intermediate reaches of the Aquidauana (Middle Aquidauana River-MAR) and the Miranda (Middle Miranda River-MMR); whereas the lowest portions of the basin was represented by the Lower Miranda River (LMR) that crosses the Pantanal floodplain.

### 3.2. Land Use and Cover

Data on the spatial distribution of land use and cover (LUC) were provided in shape file by the Socio-Environmental Institute of the Upper Paraguay River Basin (BAP)-SOS Pantanal. The LUC map for the year 2002 in a 1:50.000 scale was generated based on visual interpretation of Landsat TM satellite imagery and other ancillary data set provided by the Brazilian Program of Conservation and Sustainable Use of Biological Diversity (PROBIO), coordinated by the Ministry of Environment [31]. The monitoring for the years of 2008, 2010 and 2012 [32] followed the same technical procedures and were based on the LUC map of 2002 [31]. Only for the year of 2012, the LUC map was generated based on *Resource-Sat*-1 *LISS III*, which have similar spatial and spectral characteristics [32]. Long-term land use change studies frequently do not allow quantitative field validation, principal of historical landscape stages [33]. The methodology adopted in the works of interpretation of the images of satellite allowed corrections in the period from 2002 to 2012, giving the mapping greater reliability regarding detected changes. In areas where Landsat/Resource-Sat interpretations were doubtful, class identification and extensive qualitative validation were conducted by regional experts using high-resolution satellite data such as QuickBird and World View available within Google Earth and CBERS HRC imagery [31]. Detailed LUC were grouped into 14 classes, seven for anthropogenic areas, six for remaining areas of native vegetation and one representing water bodies (**Figure 2**). Anthropogenic areas refer to the suppression of native vegetation by: urban influence, anthropogenic change, natural change/management, degraded by mining, grazing, agriculture and plantation forestry. The remnants of native vegetation are classified according to phytogeographical aspects and vegetation characterized by the dominant life form (*i.e.* herbaceous, shrub or tree) [32]. The six classes for native vegetation are: forest formations, forest savanna (cerradão), woody savanna (cerrado*sensustricto*), grassy-woody savanna (campo), steppe savanna (Chaco) and the vegetation with riverine influence.

### 3.3. Quantifying Spatial Patterns

We quantified spatial landscape patterns throughout the Miranda basin and its six watersheds for the years 2002, 2008, 2010 and 2012, using nine (9) landscape metrics (**Table 1**). These indices or metrics describe aspects of remnant vegetation

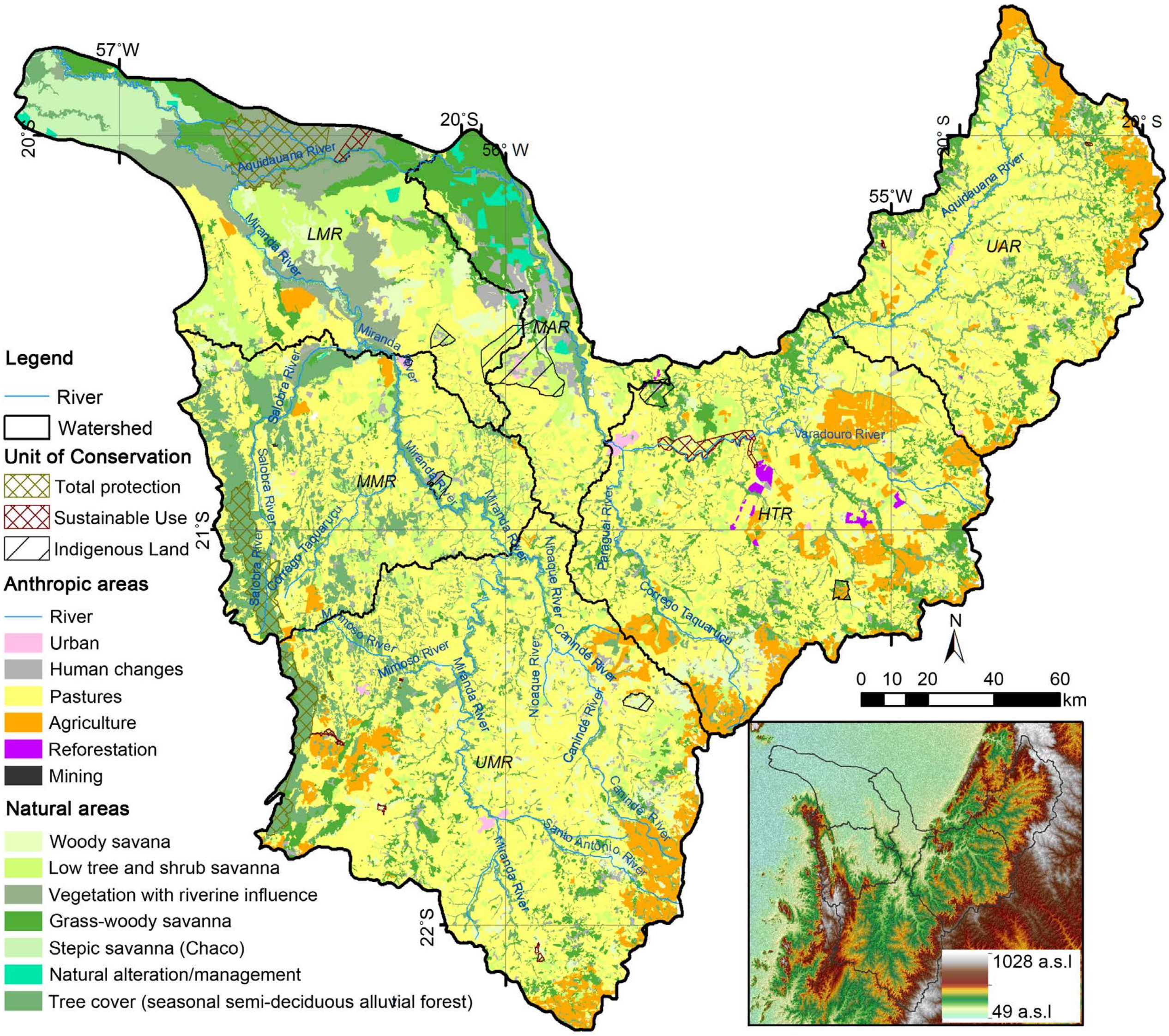


Figure 2. Land use classification of the Miranda River hydrographic Basin in 2012. Inset, topographic map of the Miranda basin. Source: SOS Pantanal (2014).

patch mosaic composition and configuration, *i.e.*, area, density, size, edge, shape, connectivity and diversity [15] facilitating monitoring human impacts on the natural landscape [18] [19]. The indices used in this study are described in **Table 1**. They are based on the concept of *patches,* that is, landscape elements that differ in structure and composition from its matrix or surroundings [15]. In this study, patches are considered the remaining fragments of the 6 classes of native vegetation surrounded by areas of human use, such as exotic grasslands and agriculture. The year 2012 was the reference, considered as the current spatial situation of the landscape.

The area of the class (CA) corresponds to the area occupied by the savanna and forest fragments. The average fragment size (MPS), the patch size standard deviation (PSSD) and the number of patches (NumP) are key indices for landscape structure analysis and indicate the way in which a landscape is fragmented

Table 1. Landscape patterns metrics used to describe aspects of the composition and configuration of the Miranda River Hydrographic Basin. Source: [34].

| Group | Abbreviation | Metric | Unit | Observation | Formula |
|---|---|---|---|---|---|
| Area | CA | Total (Class) area | $Km^2$ | Sum the patches in all class areas or the fragments of native vegetation present in the area. | $\mathrm{CA}=\sum_{i=1}^{n} C_i$ |
| Density and size | NUMP | Number of patches | Unit | Total number of patches in the vegetation class | $\mathrm{NUMP}=\sum n_i$ |
| | MPS | Mean patch size | $Km^2$ | Sum of the total size of all patches divided by patch number | $\mathrm{MPS}=\frac{\sum_{j=1}^{n} a_{ij}}{n_i}$ |
| | PSSD | Patch size standard deviation | $Km^2$ | Distribution of variance of patch size | $\mathrm{PSSD}=\frac{\left\lvert \sum_{j=1}^{n} \lvert a_{ij} - \left(\frac{\sum_{j=1}^{n} a_{ij}}{n_j}\right) \right\rvert^2}{n_i}$ |
| Edge | ED | Edge density | $m \cdot ha^{-1}$ | Quantity of length of edge (TE)relative to total area (CA) | $\mathrm{TE}=\sum_{i=1}^{n} e_i$ $\mathrm{ED}=\frac{\mathrm{TE}}{\mathrm{CA}}$ |
| Shape | MSI | Mean shape index | adimensional | Measures the complexity of patch form. Is equal to 1 when all the patches are squares and increases with the growth of irregularity in the form of the patch | $\mathrm{MSI}=\frac{\sum_{j=1}^{n}\left(\frac{0.25 p_{ij}}{\int^{a} ij}\right)}{n_i}$ |
| Connectivity | MNN | Mean distance to nearest neighbor | meters | The mean nearest neighbor Euclidian distance between closest patches | $\mathrm{MNN}=\frac{\sum_{j=1}^{n'} h_{ij}}{n'_1}$ |
| | CONN | Connectivity | adimensional | Number of functional connections between all fragments over a determined distance, divided by the total number of possible connections between these fragments | $\mathrm{CONN}=\left[\frac{\sum_{j\neq k}^{n} c_{ijk}}{\frac{n_i(n_i-1)}{2}}\right](100)$ |
| Diversity index | SDI | Shannons diversity index | adimensional | Estimate of the relative abundance and variability of the different types of vegetation | $\mathrm{SDI}=\sum_{i=1}^{S} n_i \ln n_i$ |

[34]. To allow comparisons between the 6 watersheds of different sizes (**Table 2**), the number of patches in each watershed was normalized by the area of the largest watershed of the Miranda basin (*i.e.* the Upper Miranda River). The metric *border extent* (ED) is based on the calculation of the total perimeter edge of fragments (km) per unit area (ha), playing a key role in defining ecotones, ecoclinas and ecotypes [35] Besides ED indicates the variation in heterogeneity and the extent of landscape fragmentation [36], because the amount of edge in a lands capre generally increases with fragmentation [18]. The shape index (MSI) was used to evaluate changes in patch shape, from complex to simple forms associated with anthropic land use classes, such as agricultural or urban areas [18]. The MSI ranges from 1, for patches with a very simple shapes (squares) and can increase infinitely to reflect complex patch forms [35] [37]. The index of connectivity (CONN) measures the number of connections between patches or

Table 2. Socioenvironmental characteristics of the 6 watersheds of the Miranda River hydrographic Basin.

| | *Upper Aquidauana Rive* | *Headwaters of Taquaruçu River* | *Upper Miranda River* | *Middle Aquidauana River* | *Middle Miranda River* | *Lower Miranda River* |
|---|---|---|---|---|---|---|
| **Bioma** | Cerrado | Cerrado | Cerrado | Cerrado/Pantanal | Cerrado | Pantanal |
| **Mean altitude, m** | 440 | 294 | 344 | 231 | 380 | 109 |
| **Watershed area, km$^2$** | 6582.18 | 9293.41 | 11,547.73 | 2886.46 | 5976.58 | 6804.35 |
| **Area occupied by remnant vegetation, %** | 39 | 37 | 31 | 60 | 46 | 76 |
| **Area occupied by alluvial forests, %** | 6 | 1 | 8 | 1 | 12 | 10 |
| **Dominant vegetation type** | Steppe-savanna | Forest savanna | Alluvial forest | Steppe savanna | Deciduous and semideciduous forest | Vegetation with riverine influence |
| **Dominanthuman-activity** | Agriculture | Agriculture | Agriculture | Human activity | Ranching | Ranching |

fragments of native vegetation within a distance of 1000 meters of one another, through both the inter-dispersion of patch types [38] (e.g. mixture of different patch classes), and patch dispersion (*i.e.* spatial distribution of patch classes) [39]. High CONN values indicate landscapes with patches that are either numerous, or large and close together, whereas low values indicate landscapes with small and/or isolated units [18]. The distance of 1000 meters between fragments used in the current study was based on species with intermediate capability for movement, such as the following bird species: *Amazon aestiva* (Blue-fronted Amazon), *Psarocoliusdecumanus* (Crested Oropendola) and *Campylorhamphustrochilirostris* (Red-billed Scythebill) [40]. The metric distance from the nearest neighbor (MNN), unlike CONN, analyzes by how much a fragment is isolated from another in terms of Euclidian distance. From the landscape ecology perspective, it refers to the inaccessibility of a habitat fragment for organisms migrating from other patches [41] and is measured by the nearest edge-to-edge distance [42]. The Shannon Diversity Index (SDI) was calculated to assess the physiognomic variability of the remaining natural vegetation in the analyzed polygons, *i.e.*, the whole basin and in each watershed. The value zero is present only when the landscape contains a single class, increasing as the number of classes increases and the proportion of each class within the landscape becomes more equitable [38].

*ArcGIS* 10.2 software, with the extention *Patch Analyst* [43], except for the connectivity index, which was calculated using *FRAGSTAT* 4.2 [34].

### 3.4. Indicator of Landscape Integrity

The indicator of integrity was used to detail the transformation processes occurring in the Miranda basin, helping to monitor the impacts of landscape changes on fragmentation processes. For this, the 9 landscape metrics (*M*) calculated for each watershed were combined into an addition/subtraction equation to create the Index of Landscape Integrity (ILI) (Equation (1)) [44]. Each index was previously transformed to values ranging between zero (0) and one (1). The equation sign used (addition or subtraction) was based on the relationship of the *n* metrics, negative or positive, within the landscape fragmentation processes, as based on the literature [3] [27] [45].

$$\text{ILI} = \sum (Mn) \tag{1}$$

## 4. Results

### 4.1. Loss of Native Vegetation Fragments in the Miranda Basin

More than half of the Miranda basin is deforested, with loss of its native vegetation of more than 1880 square kilometers in the period of 10 years, corresponding to a reduction of 4.4% of the total area.

Exotic pasture was the most proeminent landuse, and also the activity which most increased between 2002 and 2010 (**Figure 3**). In 2002, 47% of the landscape was composed of pasture (20,215.04 $km^2$), by 2010 this was 50.57% (21,723.34 $km^2$). **Figure 3(a)** shows that between 2010 to 2012 pasture cover decreased by 153 $km^2$. This was the period during which agriculture showed the strongest growth (1.1% of its original area, reaching 2,993,399 $km^2$ in 2012). The remaining vegetation with largest coverage in the basin are the forest formations with 4701 $km^2$, followed by grassy-woody savanna (3984.311 $km^2$) and woody savanna (3752. 84 $km^2$). Vegetation types in the Miranda basin maintained the same order of dominance over the years, although their loss rates varied. The biggest losses occurred for the grassy-woody savannas, with a decrease of 1.55% since 2002 (**Figure 3(b)**). Woody and forest savannas were reduced by 1.4% and 0.8%, respectively. These losses mainly occurred from 2002 to 2008, a period that coincides with an increase in exotic pastures (**Figure 3(a)** and **Figure 3(b)**). For instance, the annual loss rate for tree cover was 0.09% from 2002 to 2008; dropping to 0.03% from 2008 to 2010 and to 0.02% from 2010 to 2012. Cover of steppe savanna and vegetation with fluvial influences were not reduced.

### 4.2. 10-Years Changes in Lanscape Integrity

The current progress of vegetation fragmentation in the basin was analysed using a synthetic index (Indicador of Landscape Integrity-ILI) obtained from the nine assessed landscape metrics (**Figure 4**), which provides an empiric indicator of the state of landscape integrity (Equation (2)).

$$\text{ILI} = \text{CA} + \text{SDI} + \text{CONN} + \text{MSI} + \text{MPS} - \text{MNN} - \text{ED} - \text{Nump} - \text{PSSD} \tag{2}$$

The indicator varied from −2.12, indicating the lowest landscape integrity state, to 2.88, indicating highest landscape integrity related to fragmentation processes and native vegetation loss.

The watersheds Headwaters of Varadouro-Taquaruçu (HTR) (−2.12), Upper Aquidauna River (UAR) (−1.83) and Upper Miranda River (UMR) (−1.70), which are located in the high lands of the basin, with a predominance of agricultural activities, presented the lowest indices of landscape integrity (**Figure 5**). These resulted from remnant vegetation covering small areas (28%, 26% and

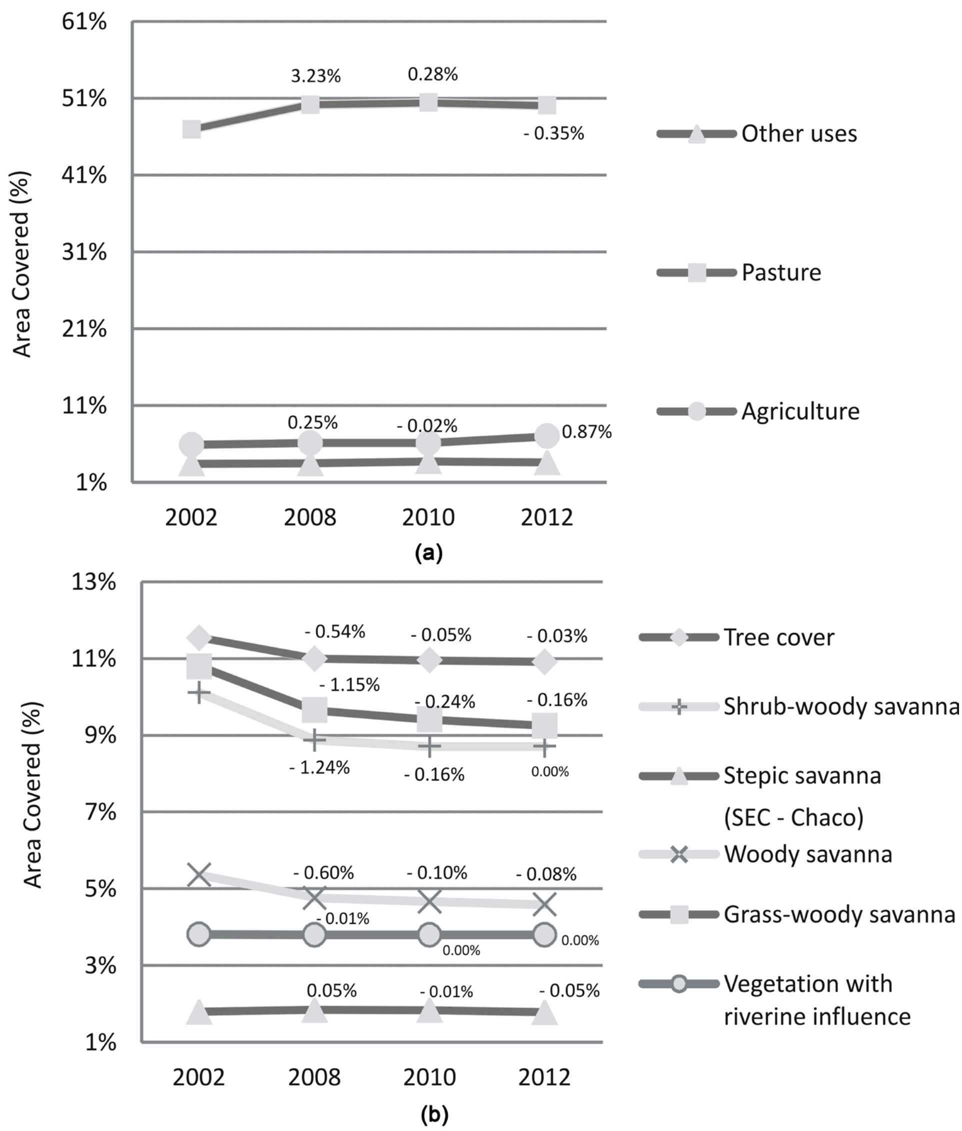


**Figure 3.** (a) Changes in the proportion of fragments of native vegetation in the Miranda River Hydrographic Basin between 2002 and 2012, and (b) changes in human use. Positive and negative variation values indicate gains and loss in land cover over time.

29%, respectively) (Figure 4(a)), small pacht size (1.54 to 1.67 $km^2$) (Figure 4(b)) and a large number of fragments (1530, 2137 and 1101, respectively) (Figure 4(d)) within the basin. Besides, these watersheds had the highest value for fragments edge density (Figure 4(e)) and the most isolated fragments, apart each other by 206 m (UMR) to 242 m (UAR) (Figure 4(g)).

On another hand, 75% of the native vegetation remains in Lower Miranda River (LMR) watershed, followed by Middle Aquidauana River (MAR) (50%) and Middle Miranda River (MMR) (46%) (Figure 4(a)), highlighting the greater landscape integrity of the middle-lower basin. The predominance of pasture activities and existence of protection areas might have guaranteed their higher landscape integrity and proportion of alluvial forest among the watersheds (Table 2). LMR presented a high coverage by natural vegetation, large fragments,

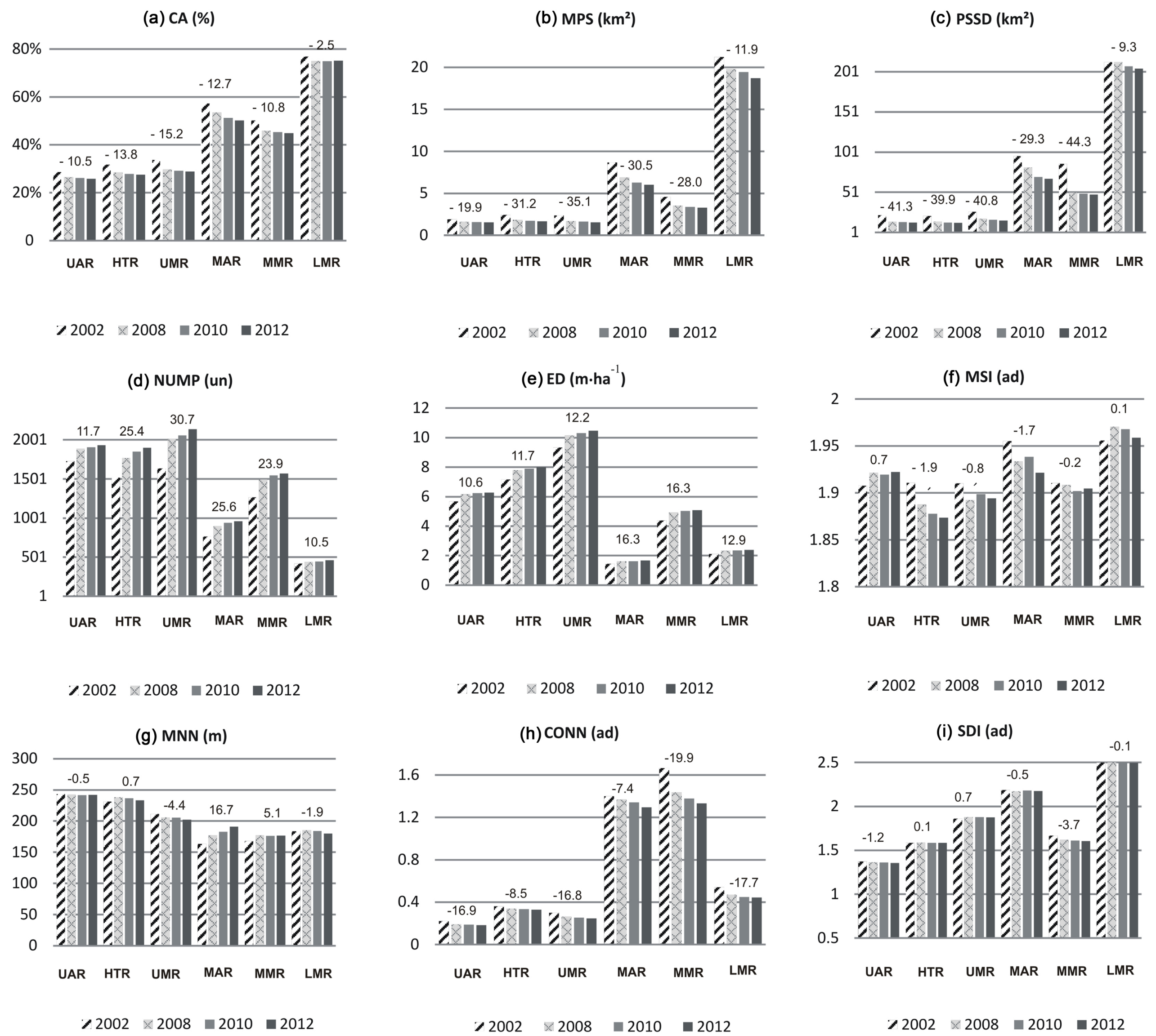


Figure 4. Changes in the landscape configuration and composition in the Miranda River Hydrographic Basin between 2002 and 2012 evaluated using 9 metrics, as follows: (a) Patch Area; (b) Mean Patch Size; (c) Patch Size Standard Deviation; (d) Number of Patches; (e) Edge Density; (f) Mean Patch Shape; (g) Mean Nearest Neighbor Distance; (h) Patch Connectivity Index; (i) Shannon Diversity Index. Losses and gains are shown as percentage change these values over the 10 years. Negative variation values indicate loss.

high habitat diversity and low isolation between its remaining fragments, which gave it the highest landscape integrity (2.77) (Figure 5). This watershed, although highly-vegetated, showed low connectivity (Figure 4(h)) due to the low number of small size fragments.

All six watersheds showed an increase in the number of fragments throughout the observation period (Figure 4(d)). Total area covered by natural vegetation deacresed, mean and spatial variation in patch size were reduced (Figure 4(b) and Figure 4(c)) and connectivity among fragments decreased (Figure 4(h)). The fragmentation processes during the 10-years were more intense in the watersheds Middle Aquidauana River and Varadouro-Taquaruçu Headwaters, with

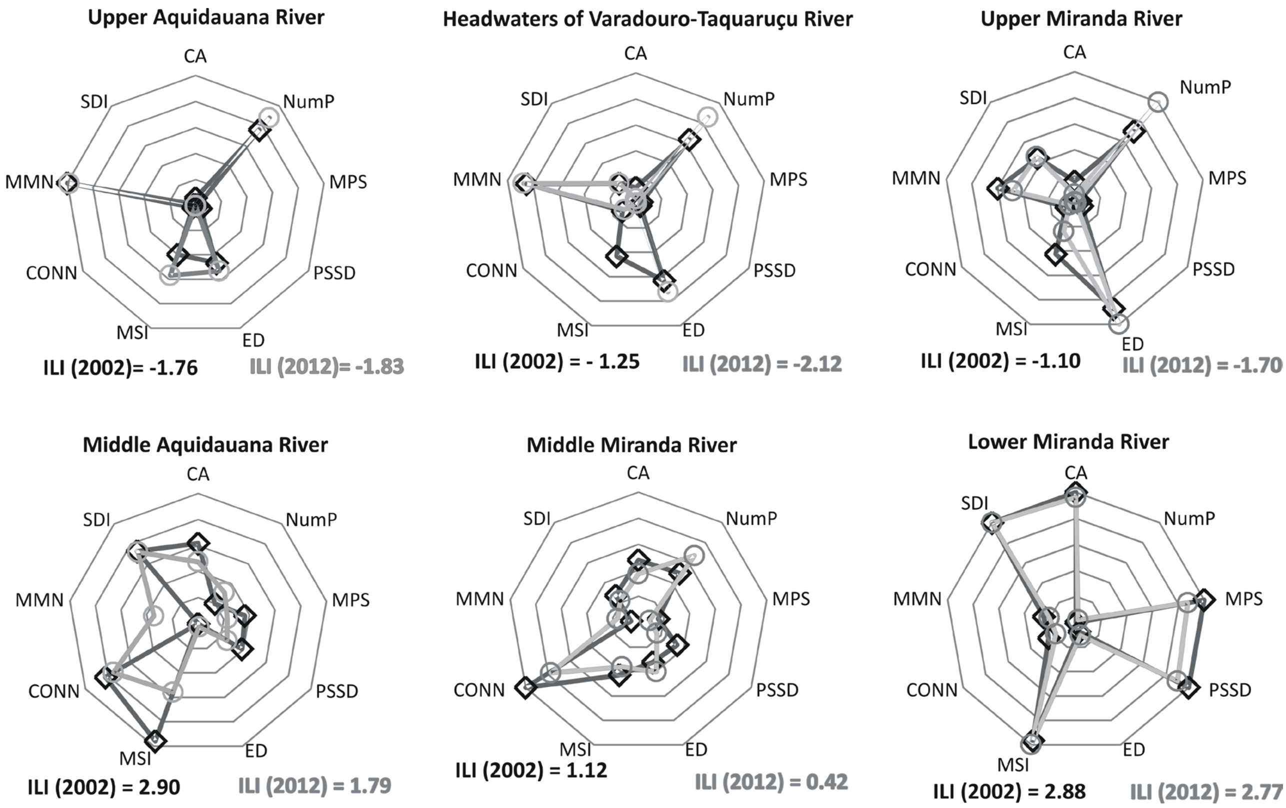


**Figure 5.** Temporal changes in landscape integrity in the 6 watersheds in the Miranda basin. Indicador of Landscape Integrity (ILI) was obtained from nine landscape metrics, which provides an empiric indicator of the state of landscape integrity. The metrics were transformed into values ranging between 0 and 1. CA: proportion of remaining vegetation; NUMP: number of fragments, MPS: mean patch size, PSSD: standard deviation of patch shape, ED: edge density MSI: mean shape index, CONN: connectivity, MNN: distance from the nearest neighbor, SDI: Shannon diversity. ILI varies from −2.12, indicating the lowest landscape integrity state, to 2.88, indicating highest landscape integrity related to fragmentation processes and native vegetation loss.

land use convertion changing patch shapes to more regular forms and increasing isolation of the remaining fragments. The Headwaters of Varadouro-Taquaruçu (HTR) was in better integrity state in 2002 (ILI = −1.25) than its neighborhood watershed Upper Aquidauana River (UAR) (ILI = −1.76) (Figure 5), indicating the rapid degration processes happened in HTR associated with reduction of the total occupied remnant area and fragmentation. Number of fragments and patch size were the landscape parameters that have changed the most over time. In the Upper Miranda River (UMR), the number of fragments changed from 1635 fragments in 2002 to 2137 in 2012, an increase of 30.70% (Figure 4(d)). The fragmentation process that caused the fragment isolation, often decreased overall connectivity. Figure 6 demonstrates how this process occurred in a 25 $km^2$ hexagon within the Miranda basin, from 2002 to 2012. All watersheds suffered reduced connectivity in this period. Watershed Middle Miranda River (MMR) stood out, with a decrease of 19.92%, followed by watersheds UAR (16.96%) and UMR (16.83%) (Figure 4(h)). The overall trend in vegetation diversity (SDI) was a slight decrease over time (Figure 4(i)). In the watershed MMR, for example, SDI had the greatest drop in vegetation diversity, decreasing from 1.66 to 1.60 between 2002 and 2012, a reduction of 3.7%.


Figure 6. Exemple of loss of connectivity in the Miranda River hydrographic Basin.

## 5. Discussion

Human activities, driven by a variety of socio-economic, technological, cultural and political factors [7] [46] [47] have driven changes in landscape patterns in Brazilian biomes threatening its cultural and ecological integrity [27] [48] [49]. In the current study, we investigated the process of fragmentation and loss of savanna and forest formations within the Miranda Basin between 2002 and 2012. We did this using landscape metrics and integrated index which allowed the spatial and temporal evaluation of ecological integrity of the watersheds landscape.

In the Miranda basin 4.4% of the native vegetation was removed between 2002 and 2012. The most extensive changes to the spatial patterns of remaining vegetation were seen between 2002 and 2008 (**Figure 7**), a period of great increase in livestock occupation. The loss of native vegetation in the Cerrado over the last 20 years is attributed to the expansion of agrobusiness, mining and urban growth [48] [50]. Natural vegetation removal was recorded more intense in the Miranda basin in 1972, likely because of federal and state government programs to encourage the expansion of the agricultural frontier [51]. Decreases in deforestation rates over time observed in Miranda basin are probably a result of the reduction of remaining natural vegetation in the region over the last years. The grazing lands that dominated most of the basin in the last decades, more recently (2010-2012) are being converted to agriculture areas, especially in the basin uplands, due to better prices of these commodities.

The general trends in natural vegetetation cover changes in the Miranda basin over the 10 years of study were: a reduction of native vegetation fragments; decrease in fragment size and increase in density; decreasing complexity of the fragments forms; decreased connectivity and increased isolation; and decreased diversity of habitats (*i.e.* vegetation classes). Other studies have shown similar relationships between reducions in the amount of remaining vegetation and the landscape fragmentation process [27] [52]. This trend for habitat to become divided into progressively smaller and more isolated units directly affects biodiversity conservation and environmental quality [27]. As a result, it can foster

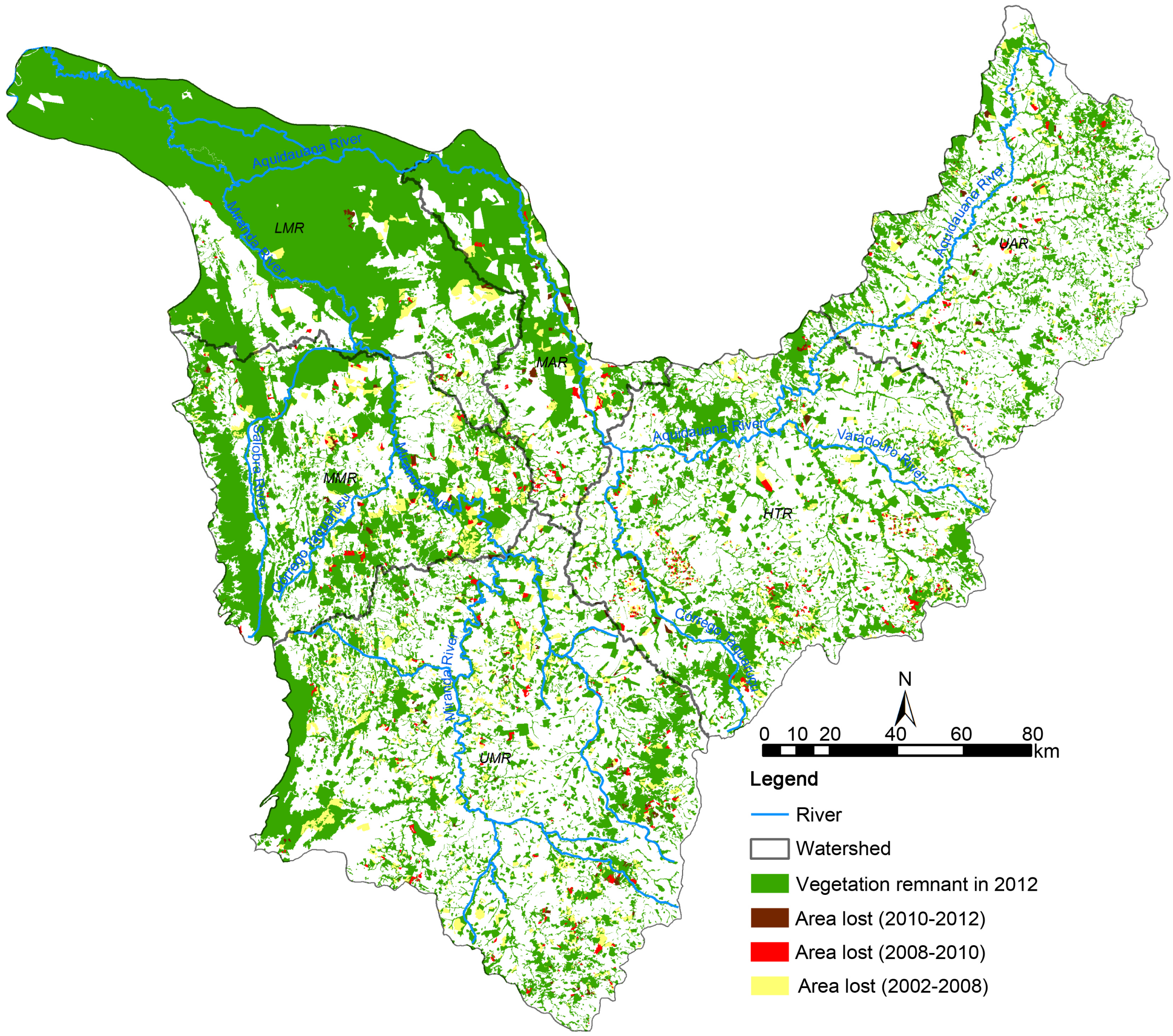


**Figure 7.** Loss of native vegetation in the Miranda River hydrographic Basin during 2002, 2008, 2010 and 2012.

biological invasions [53] [54], reduce diversity of available ecological niches, change the microclimate of habitats [17] and cause local species extinction due to the interruption of gene flow between local populations [3] [5]. Accordingly, it is important to understand the spatial context of the fragments, because landscape changes modify the surrounding environment of the remaining patches as the fragmentation process proceeds [49].

The consequences of deforestation for landscape configuration vary between regions in response to the amount of native vegetation remaining in the landscape, the socio-economic factors that lead to deforestation and differences in environmental and physical characteristics [6] [50]. The differences in the process of fragmentation and vegetation loss between the watersheds appear to be linked, in part, to the geomorphology and edaphic heterogeneity found in the basin. The headwaters of Aquidauana (UAR), Taquaruçu (HTR) and Miranda (UMR) rivers which constitute areas of Plateaus with predominance of crop farming are more fragmented and have a reduced amount of remaining savanna and forest. In such a situation of advanced deforestation, the isolation of the remaining vegetation exerts strong pressure on regional biodiversity [3] [55]. In contrast, the watersheds Lower Miranda and Middle Aquidauana Rivers, part of the Pantanal wetland, show greater landscape integrity, coupled with the highest proportion of remaining vegetation, the presence of large fragments (>50 $km^2$) and lower isolation between fragments (180 m and 191 m, respectively). Watershed Middle Miranda River has the third highest integrity level within the whole Miranda Basin. It is located among the Serra da Bodoquena and the transition from the Maracajú-Campo Grande Plateau to the Pantanal floodplains [56]. The steep slopes of the landscape morphology and the presence of the Serra da Bodoquena National Park should have guaranteed higher preservation levels of native vegetation. However, the presence of fertile soils on basaltic formation of Serra de Maracajú, is triggering a current conversion pressure of dry forests found in this region, which has already resulted in a decrease of the connectivity between remaining fragments. Mostly present along and at escarpment ramps, these forests, even though protected by law, continue to be eliminated due to the expansion of livestock, agricultural activities, and logging for civil and industrial use (e.g. charcoal production) [57].

The good state of landscape integrity observed in the Lower Miranda River (LMR) might have resulted from several factors: 1) about 72% of its area are in the Pantanal Wetland and under the influence of an annual flood pulse, which physically limits the expansion of crop farming and, favours extensive cattle ranching on native grasslands; 2) in this watershed there are two strictly protected conservation areas, the Pantanal of River Negro State Park and the Fazenda Santa Sofia Private Natural Heritage Reserve, which together occupy about 7% of the area; and 3) 84% of its area is considered a priority area for conservation by the Ministry of Environment, due to the occurrence of endangered species such as Cock-tailed Tyrant (*Alectrurus tricolor*), Black-and-white Monjita (*Heteroxolmisdominicana*), Chestnut seedeater (*Sporophilacinnamomea*), Reticulated or Fire Freshwater Stingray (*Potamotrygon falkneri*), Janguar (*Pantheraonca*) and Puma (*Puma concolor*) [58]. Protected areas are an integral component of biodiversity conservation policy, and have become a center-piece of global efforts to reduce carbon emissions from tropical deforestation (Scharlemann *et al*., 2010) and to contribute to climate change mitigation [59].

The Middle Aquidauna River (MAR) watershed is also largely (67%) located within the Pantanal Wetland. However, despite representing one of the areas with the highest levels of landscape integrity, the increasing number of fragments and reduced patch sizes are the results of growing mining activities, which indice a greater vulnerability to deforestation and vegetation degradation.

Seasonal deciduous and semideciduous forests and forest–savanna forest transitions are the predominant formations of the remaining natural vegetation in the Miranda basin (11%). Though the cover loss over the 10 years study period was limited (0.6%), it represents huge losses for biodiversity and landscape connectivity. The loss of connectivity can affect the mobility of groups that are specialists in the forest habitats of the region [60], such as bird species that rely on riparian forest corredors to move between distant habitats in favorable phases of the year or during mating seasons [61] [62]. In general, isolation acts negatively on species richness by reducing immigration rate. Species that manage to survive in isolated fragments tend to become dominant [63] and thus habitat diversity decreases by a decrease of richness and biological evenness. Since these forests generally occupy protected areas in the basin, such as river banks, any reduction implies in heavy losses for the regional biodiversity.

Savanna vegetation suffered the highest areal reduction in the last 10 years within the basin, in special, the native grasslands. Between 2002 and 2012 the reduction was 1.55% with substitution of natural grasslands mostly by exotic pasture. Similarly, Rocha *et al.* [64], analyzing deforestation in the Cerradobiome between 2002 and 2009, found a reduction rate for native grasslands of 3.63%. The conversion of native grasslands to planted ones, usually formed by grasses of African origin (e.g. *Brachiaria* spp.), is considered the major forms of vegetation change in the Cerrado. Causing an immediate reduction of local species diversity, it increases the risk of invasion by alien species and burning [65]. These impacts on wetland habitats deserve special attention, because it directly affects the quantity and quality of water available in the watershed [25]. The conservation of these wetlands can help ensure water security of the country against negative climate change scenarious, as well as meeting national and international agreements (Convention Ramsar, Iran, 1971) to protect Brazilian wetlands [66].

In Brazil over the last 40 years, environmental policy had made great advances (Law N˚. 4771 of 15/9/1965) with the creation of many conservation units and delimitation of protected areas on private property. However, the recent loosening of legislation was a strongly retrograde step (e.g. Brazil's New Forest Code 2012), reducing protected habitats, such as riparian forests, forests on slope greater than 45˚ and in legal reserves [67]. It shows that the expansion of agricultural frontiers still commands the future of Brazil's natural landscapes. Conservation strategies for native vegetation remnants must have broad prospects, given that ecosystems and their environmental services are not isolated in landscapes altered by anthropogenic uses and operate at the large-scale, facilitating connectivity between natural and anthropogenic ecosystems [68].

Based on the state of integrity in the Miranda basin, it can be seen that deforestation is increasing, and that resulting changes in the landscape configuration tend to be more evident in areas with higher proportions of remaining native vegetation. In this regard, the watersheds that comprise most of the lowland areas (LMR and MAR), and the watershed which houses the Serra da Bodoquena (MMR), clearly require further biodiversity conservation policies [69]. This is supported by results of this study and other research on the status of regional habitats and their biodiversity [23] [27] [33] [34] [56]. Areas of Permanent Preservation (APP) and Legal Reserves (RL) form one of the main mechanisms for the protection of biodiversity in Brazil [70]. Those present in the Miranda basin require intensive supervision so that the representativeness of the remaining vegetation of the Brazilian biomes also is guaranteed on private property.

## 6. Conclusions

The removal of native vegetation in the Miranda basin over the studied 10 years period (2002-2012) was 4.4%. The deforestation during this time mainly resulted from the expansion of livestock and agriculture activities. Although agriculture within the study area currently occurs to a lesser extent, it has the potential to grow via the conversion of exotic pastures and advance in lowland areas that currently still retain substantial native vegetation cover.

The loss of native vegetation occurred mainly in grassy-woody savanna, and in semideciduous and deciduous forests, resulting in strong impacts on landscape connectivity between the plains and the plateau.

The main consequences of vegetation suppression on landscape patterns were increase in number and isolation of fragments and higher vulnerability of the remnants to external pressures, such as fire and invasions. Headwater areas had become more fragmented, while fragmentation is lower in the lowlands. However, although native vegetation is better preserved in the lowlands, those exhibited a higher vegetation loss during the observation period, warning to the need of creating legal instruments that guarantee the wise use of natural and maneged spaces.

The conservation of the remaining native vegetation should be ensured by maintaining the connectivity of vegetation mosaics, both within protected areas and outside them. Legal instruments such as resolutions, normative instructions, and mainly state and municipal laws and decrees, as well as the participation of the farm owners creating privete reserves should help the conservation of these areas in order to regulate the sustainable use of the landscape. It is imperative that government, owners and society in general understand that the limit of sustainability of the Miranda hydrographic basin has already been exceeded in most of its area, undermining their resilience and biodiversity conservation.

We recommend an intense recovery program for headwaters and aquifer recharge areas, as well as riparian forests, especially in the watersheds Upper Aquidauana River, Headwaters of Varadouro-Taquaruçu Rivers and Upper Miranda River to avoid the future compromising of water production. Besides, we also recommend the maintenance and recovering of the connectivity of the current remaining patches of natural vegetation corridors (**Figure 5**) and that the watersheds Middle Aquidauana River and Lower Miranda River should keept conserved by a program of zero deforestation and through specific laws that incoporate the consolidated scientific knowladge about wetland ecosystem functioning, like the Pantanal [71].

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