Reg Environ Change (2018) 18:21–32
https://doi.org/10.1007/s10113-015-0824-z

ORIGINAL ARTICLE

The role of private rural properties for conserving native vegetation in Brazilian Southern Amazonia

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Received: 25 November 2013 / Accepted: 27 May 2015 / Published online: 6 August 2015

Abstract The State of Mato Grosso in Brazil has undergone intensive land use changes over the past decades. Native ecosystems have been converted into agrosystems for the production of cash crops and cattle. The Brazilian Forest Code advocates full protection of specifically sensitive habitats, and it also safeguards a fixed percentage of native vegetation known as "Legal Reserves" (LRs) inside private rural properties. As part of Brazilian Legal Amazonia region, in Mato Grosso, these percentages account for 35 % of savannas and 80 % of forests found inside each rural property. Here we analyze at the scale of the three biomes: Cerrado, Amazonia and Pantanal, the changes in native vegetation cover (NVC) from 1992 to 2007 and the representativeness of NVC types within the LRs, as well as the role of LRs for general landscape configuration and conservation. In Mato Grosso, 90 % of all studied NVC types are represented inside LR patches. Legal Reserves also accounted for 37 % of the total protected areas and for 37.8 % of all remnant NVCs found in Mato Grosso in 2007. The importance of LRs for landscape structure varied greatly according to biome, but it is noteworthy that LRs were generally missing in highly deforested zones. The relative small size of LRs in all biomes (55 to 64 % of them are ≤12 ha) makes them specifically vulnerable to further changes in land use. Considering the current tendency of ongoing fragmentation, the importance of LRs for landscape connectivity should be increased, specifically by improving the network of corridors between these remnant native vegetation areas.

Keywords Amazonia · Biome · Conservation · Deforestation · Legal Reserves

Editor: Marc J. Metzger.

Electronic supplementary material The online version of this article (doi:10.1007/s10113-015-0824-z) contains supplementary material, which is available to authorized users.

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Introduction

Large-scale landscape fragmentation has been identified as the most important cause of biodiversity losses in the tropics (Morton et al. 2005; Roy and Joshi 2002; Tabarelli et al. 2004). Throughout the last four decades, conversion of large portions of the original native vegetation cover (NVC) of savannas and forests into agricultural land and pastures has resulted in an intensive deforestation process in the Brazilian Amazonia (Morton et al. 2006; Skole and Tucker 1993; Soares-Filho et al. 2001). The State of Mato Grosso has experienced the highest deforestation rate since 1970 (INPE 2012), as a consequence of the expansion of the agricultural frontier toward the Amazonia and the Center-West regions originally promoted by the Brazilian Government (Becker 2001; Mahar 1979). Presently, one-third of the 3500-km-long "Amazon arc of deforestation" is located in Mato Grosso (Aldrich et al. 2012; Fearnside 2005; Morton et al. 2006). In Brazil, parts of the landscape are protected from this conversion by national laws. Most prominent are the strictly protected, large-sized reserves such as National Parks and other reserves on public territory (Conservation Units, CU; Indian Lands, IL). Apart from CU and IL, there are two other kinds of protected areas, resulting from the Brazilian Forest Code (BRASIL 1965, 1989), namely "Permanently Protected Areas, PPA" and "Legal Reserves, LR." Compared with ILs and CUs, the size of PPAs and LRs is relatively small. Both of the latter constitute territories, where active land management is generally not permitted or is very limited, and they have different roles in landscape conservation (Metzger 2002, 2010). The habitat-specific PPAs are more related to the conservation of water and soil resources, and they include environmentally sensitive areas like hilltops, steep slopes, riparian zones and spring mires (Metzger 2002).

The proportion of native vegetation in a rural property that must not be cleared (Legal Reserve) depends on the region where the properties are located and on the type of predominant vegetation class (BRASIL 1965). With regard to the study area (Fig. 1), the Brazilian territory is divided in two sections, the northern states plus parts of the center-west and the rest of the country. The first region roughly coincides with the hydrographical basin of Brazilian Amazonia and constitutes the so-called Legal Amazonia region. Nine Brazilian states (61 % of the Brazilian territory); including the whole Mato Grosso State, belong to it. In Amazonia, the percentage of a rural property required for LR is higher than in any other region of the country. In terms of native vegetation, the law considers two major classes: forest and savanna. In the original version of the law, 50 % of forest on each property in Legal Amazonia had to be preserved, but this figure was increased to 80 % in 1996 in order to restrain the deforestation in the region. Savannas, which normally occur as enclaves inside forests in Legal Amazonia (including the Pantanal), have a higher percentage (35 %) of LR when compared to non-Amazonian states (20 %). These percentages were kept in the New Brazilian Forest Code (BRASIL 2012).

Legal Reserves (LRs) are generally considered a very important instrument for conservation, covering large areas of the Brazilian territory, being especially important in the Amazonia and Cerrado biomes (Lele et al. 2010; Metzger 2002). However, there are no known government strategies to connect the LRs to the other protected areas in order to assure a consistent structural network of habitats. Since LRs are registered only in the areas indicated by the landowners, they tend to be disconnected from the regional network of protected areas.

Although it is taken for granted that large protected areas are the basic element of any nature conservation strategy (Gardner et al. 2009), there is increasing evidence that exclusive reserve types are not sufficient to preserve biodiversity. Rather, the connectivity of still-natural ecosystems must be provided by biological corridors and stepping stones, especially in agricultural areas (Vandermeer and Perfecto 2005, 2007). The objectives of laws and policies such as the Brazilian Forest Code of 1965 and 2012, the French Grenelle laws (Legifrance 2010, 2011) and the European 2020 Biodiversity Strategy (European Commission 2011) have integrated these insights. It is necessary to understand the fragmentation patterns of native vegetation cover in order to develop strategies for re-establishing connectivity among remaining patches, and between remaining patches with larger preserved areas. In the case of the Brazilian LRs, neither the type of habitat (e.g., as indicated by the native vegetation type) that has to be protected, nor the spatial arrangement of these reserves has been analyzed.

The aim of this study was to analyze how much individual NVCs were affected by deforestation at the biome scale over a forty-year period, and estimate how much of the remaining vegetation remains protected in the different kinds of conservation units. Specifically, we focused on the conservation unit of Legal Reserves (LR) in order to find out how strong they contributed to conservation of NVC, and we estimate how much further deforestation within the LRs would affect the conservation of the remaining vegetation in the State of Mato Grosso.

Methods

In this study, we analyzed the importance of protected areas in conserving the remnants of native vegetation cover within the three major biomes comprised in Mato Grosso:

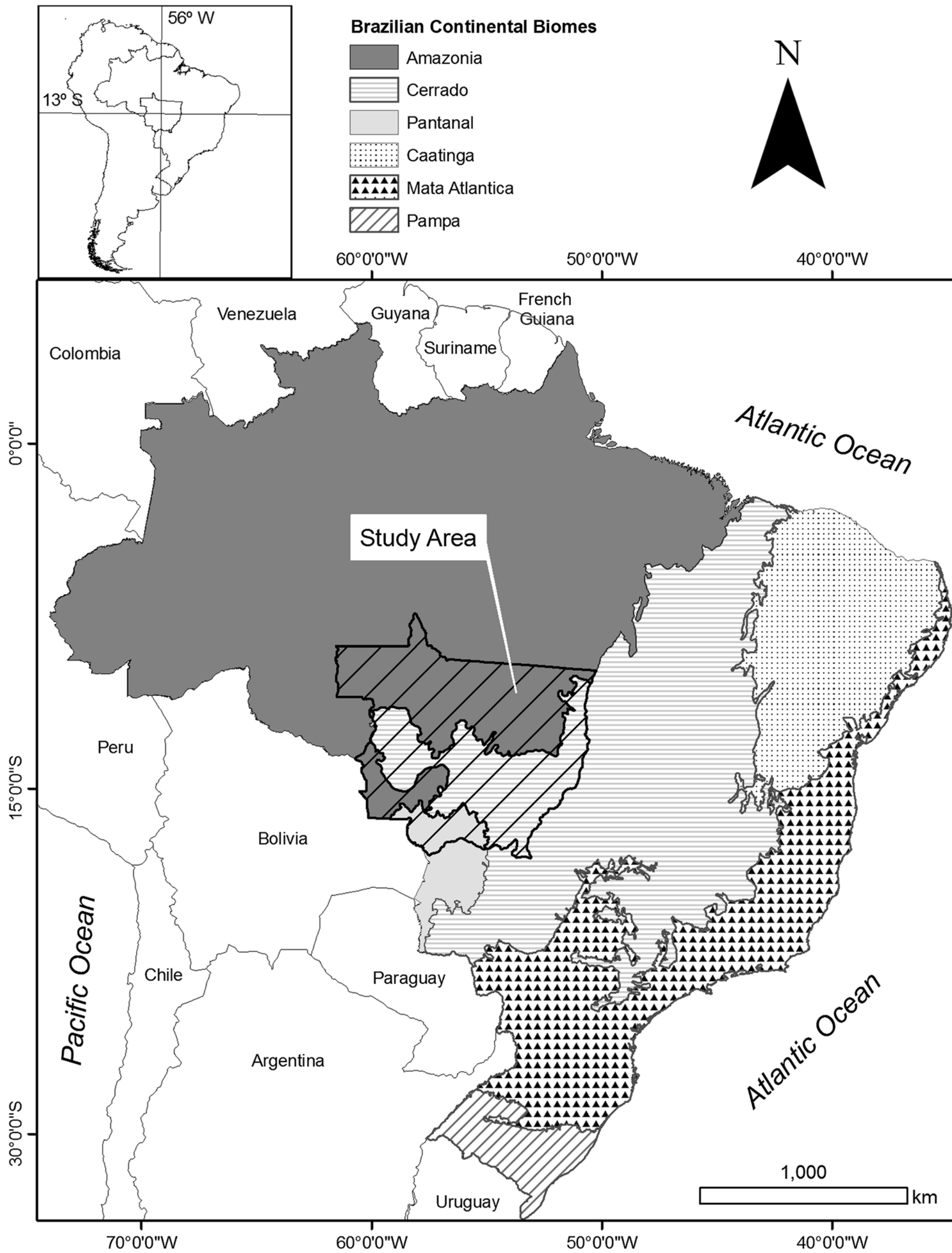

Fig. 1 Study area. The small map on the *upper left* shows the position of the State of Mato Grosso in Brazil and in South America; the large map shows the continental biomes of Brazil. In the study area (Mato Grosso, center), the Amazonia biome occurs north and south of the Cerrado; therefore, we opted to treat these sections separately

Amazonia, Cerrado and Pantanal. We selected the Biome as the core unit of our analysis because it provides an integrative view of the predominant climatic, geographic and vegetation features of the ecosystems at the continental scale (Olson et al. 2001). In order to access the conservation role of LRs, first we obtained the fragments of remaining NVC as it was found in 2006 after approximately four decades of continuous clearings. After that, we calculated the number and area of those fragments protected within Legal Reserves, Indian Lands and Conservation Units. We also calculated the number and the area of these remnants found outside such a protected areas. These calculations were performed by every NVC type found inside the three analyzed biome classified according to IBGE (1992). Finally, we analyzed the vulnerability of the LRs in face of their progressive size reduction and loss. A detailed description of the used database and the accuracy assessment are given in the Supplementary Material (Tables S1 and S2).

Study area

With a size of 90.2 million ha (Fig. 1), Mato Grosso covers approximately the combined area of continental France and Germany. The vast territory in the Western part of Brazil (7°S–5°W and 18°S–62°W) is characterized by two large contiguous high plateaus, the Parecis (16.6 million ha) and Guimarães (9.6 million ha) (Bizzi et al. 2003; Ross and Santos 1982). Mato Grosso includes large parts of the area of three river basins, the Paraguay in the South (48 %), Amazonia in the North and Northwest (14 %) and Tocantins in the Northeast (15 %) (ANA 2012). The sandy Mesozoic and Cenozoic sedimentary rocks predominating in Mato Grosso (Bizzi et al. 2003; Feitosa and Manoel Filho 2008) contain the second largest aquifer (67.7 million ha) in Brazilian Amazonia, representing up to 10 % of all groundwater in Brazil (IBGE 2011). At the lowlands (≤200 m asl), large floodplain wetlands expand at rivers such as the Guaporé (600,000 ha), Araguaia (5 million ha), Paraguay (6 million ha) and Xingu (11 million ha). Due to the absence of important geographic barriers, the large continuous transition zones harbor a high biodiversity (Junk et al. 2006; Ratter et al. 1997).

Mato Grosso represents large proportions of three out of the six major Brazilian continental biomes: Amazonia (11 %), Cerrado (18 %) and Pantanal (37 %) (IBGE 2004). Amazonia is characterized by diverse vegetation, from dense forests and open floodplain forests in the lowlands to savannas in the plateaus at an altitude of 350–1000 m asl (IBGE 2004). The prevailing climate is warm–humid with an average annual temperature of 25° C and an annual precipitation that ranges from 1500 to 2300 mm (SEPLAN 2001). The "arc of deforestation" has reached the Amazonian forest (Morton et al. 2006; Nepstad et al. 2009).

The Cerrado is characterized by a complex of savanna formations with gradual contact between deciduous and semideciduous forests on latosol and podzolic soils (Gottsberger and Silberbauer-Gottsberger 2006; Sano et al. 2008). Along the rivers and streams, narrow strips of riparian wetlands known as "veredas" with hydromorphic soils cover a large area due to the density of the stream network (Wantzen and Siqueira 2006). The precipitation ranges from 1400 to 1800 mm year^{-1}. The dry period varies from 4 to 6 months, with a hydric deficiency of 200–300 mm year^{-1} (Da Silva and Bates 2002; SEPLAN 2001). Crop plantations (soybean, corn and cotton) with intensive use of technology occur in flat terrains of the plateaus, while an extensive cattle ranching predominates at lower altitudes.

The Pantanal biome is a large, seasonally flooded Cenozoic sedimentary plain covered mainly by a mosaic of savannas, seasonal forests, xenomorphic formations and grasslands along lakes and some temporal streams. The average annual temperature is 20 °C, and the precipitation ranges from 1300 to 1500 mm year^{-1}. The dry period has 5 to 8 months, with a hydric deficiency reaching from 250 to 450 mm year^{-1}. Here, cattle ranching is the predominant land use (Junk et al. 2011; SEPLAN 2001).

Database

A database was constructed with digital maps in Shape File vector format including: (1) the Biomes of Brazil map at the scale of 1: 5,000,000 (IBGE 2004), (2) the vegetation cover map at scale of 1:1,000,000 (RADAMBRASIL 1982), (3) several 1:250,000-scale maps of the protected areas from 1999 to 2007 by the Mato Grosso State Secretary for Environment (SEMA-MT) and for Planning Economic Development (SEPLAN 2001), (4) polygons of the LRs from 1992 to 2007 by the Mato Grosso State Secretary for Environment (SEMA-MT) and (5) the annual deforestation maps at scale of 1:250,000 from 1992 to 2007 produced by SEMA-MT. All GIS data were entered into a geographic database according to the ESRI Geodatabase procedure (Booth 2002; Zeiller 2010), re-projected into the Lambert projection, and converted to raster maps with 200 × 200 m cell. Geo-processing procedures were undertaken using the ArcMap component of ArcGIS 9.3 (ESRI 2008).

Accuracy analysis of deforestation map was made by assessing the classification accuracy of 75 control points randomly distributed in each biome. A SPOT image mosaic with a higher resolution than those employed in our study was used as surrogate for ground truth data, resulting in an overall accuracy ranging from 83.3 % in the northern Amazonia to 93.3 % in the Pantanal biome. Kappa coefficients varied from 0.67 (substantial agreement) to 0.87 (almost perfect agreement) for both biomes, respectively. A detailed description of the used database and the accuracy assessment are given in the Supplementary Material (Tables S1 and S2).

Data analyses

We evaluated the spatial changes of the NVC by comparing its original configuration with those found at the end of the analyzed period (2007). Additionally, we calculated the following landscape metrics using FRAGSTATS 3.3 (Botequilha Leitão et al. 2006; McGarigal and Marks 1995): patch number (PN), class area (CA), percent of landscape (PLAND), class area reduction (CAR), total core area (TCA) and patch number increasing (PNI). Size distribution of LRs among the biomes was analyzed on the basis of five size intervals of (CA) as follows: very small (4 ha ≤ CA ≤ 12 ha), small (12 ha < CA ≤ 100 ha), middle (100 ha < CA ≤ 500 ha), large (500 ha < CA ≤ 1000 ha) and very large (CA > 1000 ha). LR patches are permanently threatened to become deforested, as they are more exposed and more dispersed than other protected areas. In order to assess the risk of elimination or reduction of LRs, we calculated their remaining total core area (TCA) in a scenario of progressive reduction of their areas at the biome scale. We calculated this metric by supposing a step-wise reduction from the border to the center of each patch of 200 m (1 pixel), 600 m (3 pixels), 2000 m (10 pixels), 2600 m (13 pixels) and 3200 m (16 pixels).

Results

Original vegetation, conservation state in 2007 and contribution of protected areas

Amazonia biome

In its original configuration, the Amazonia biome was constituted by a matrix of forests distributed in relatively few large compact patches inside which savannas subsisted as islands (Table 1; Figs. 2, 3). The forestry matrix was quite different in the northern and southern subsections, however, because a matrix of ombrophylous and semideciduous forests predominated in the North, while in the South, it was predominantly constituted by semideciduous forests. Non-forested classes constituted 32 % of southern Amazonia, while in the northern section, these classes represented only 11.4 % of the landscape. The relative abundance of non-forested areas and the absence of ombrophylous forests in the southern part are related to the dryer climate of this region (annual precipitation between 1400 and 1900 mm) compared with the northern part (annual precipitation between 1600 and 2400 mm).

Table 1 Native vegetation classes (NVC) clearings and patch number (PN)

Biome	NVC	Original NVC based on RADAMBRASIL Vegetation Map			Remaining NVC in 2007					
		PN	Area (ha)	PLAND (%)	Remaining (ha)	CLEARED (ha)	% of Total Clearings	PN	PN Increasing (%)	% of PN increasing
North Amazonia	A	61	11,921,872	28.8	7,329,904	4,591,968	34.1	18,550	30,310	41.1
	C	6	311,316	0.8	290,140	21,176	0.2	71	1,083	0.2
	D	234	2,409,788	5.8	1,848,144	561,644	4.2	3,260	1,293	7.2
	F	159	20,871,712	50.4	14,276,924	6,594,788	49.0	15,854	9,871	35.1
	P	135	985,308	2.4	897,400	87,908	0.7	520	285	1.2
	SN	31	119,392	0.3	47,064	72,328	0.5	172	455	0.4
	SO	1	58,148	0.1	57,960	188	0.0	1	0	0.0
	S	211	4,742,600	11.4	3,215,144	1,527,456	11.4	6,729	3,089	14.9
	Total	838	41,420,136	100.0	27,962,680	13,457,456	100	38,428	4,486	100
South Amazonia	C	21	254,772	4.1	80,788	173,984	4.7	681	3,143	5.9
	F	54	3,903,800	62.8	1,358,420	2,545,380	69.3	7,147	13,135	61.6
	P	17	24,288	0.4	17,248	7,040	0.2	67	294	0.6
	S	109	1,670,348	26.9	834,784	835,564	22.8	3,342	2,966	28.8
	ST	12	365,348	5.9	254,724	110,624	3.0	363	2,925	3.1
	Total	213	6,218,556	100.0	2,545,964	3,672,592	100	11,600	5,346	100
Cerrado	A	36	123,276	0.3	90,208	33,068	0.2	280	678	0.5
	C	23	590,712	1.6	180,856	409,856	2.2	1,912	8,213	3.2
	D	25	35,596	0.1	32,804	2,792	0.0	69	176	0.1
	F	274	3,980,072	10.9	2,677,712	1,302,360	7.1	4,873	1,678	8.1
	P	11	71,904	0.2	56,732	15,172	0.1	51	364	0.1
	SN	17	606,976	1.7	249,360	357,616	1.9	829	4,776	1.4
	SO	5	59,840	0.2	51,568	8,272	0.0	15	200	0.0
	S	97	31,200,852	85.1	14,930,172	16,270,680	88.4	51,995	53,503	86.6
	Total	488	36,669,228	100.0	18,269,412	18,399,816	100	60,024	12,200	100
Pantanal	C	28	181,136	3.3	123,192	57,944	4.3	397	1,318	5.7
	F	76	621,348	11.4	511,572	109,776	8.1	777	922	11.2
	S	126	4,585,196	83.8	3,400,296	1,184,900	87.6	5,768	4,478	83.0
	T	5	82,748	1.5	82,672	76	0.0	5	0	0.1
	Total	235	5,470,428	100.0	4,117,732	1,352,696	100	6,947	2,856	100

Increment. Forest classes are italicized

PLAND Percentage of biome occupied by a given NVC, *A* ombrophylous open forest, *C* seasonal deciduous forest, *O* ombrophylous dense forest, *F* seasonal semideciduous forest, *SN* contact zone savanna/seasonal forest, *SO* contact zone savanna/ombrophylous forest, *S* savanna, *ST* contact zone savanna/steppe-like savanna, *T* steppe-like savanna, *P* pioneer formation

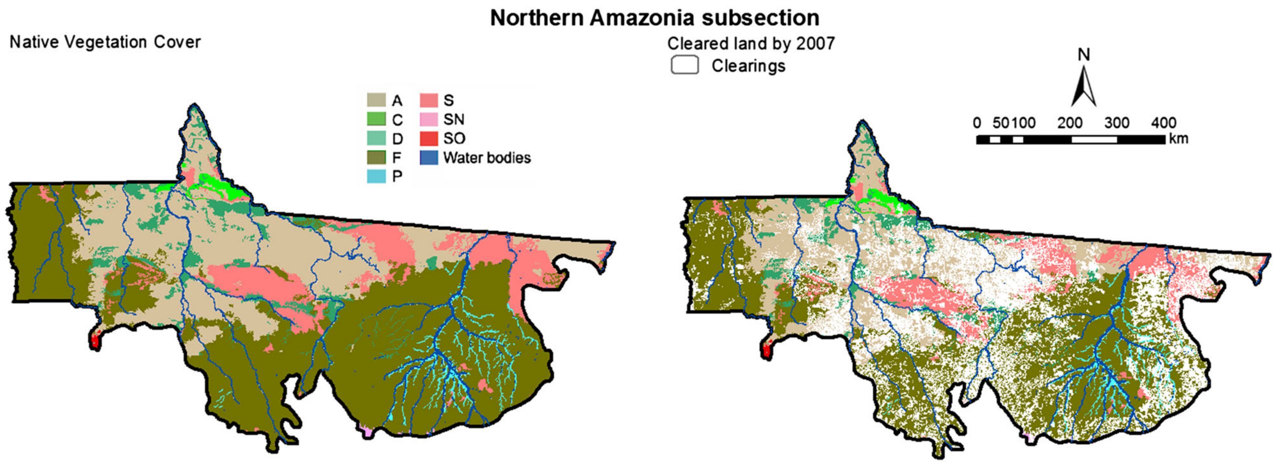

Fig. 2 Native vegetation cover (*left*), remaining vegetation and clearings by 2007 (*right*) in the northern section of the Amazonia Biome in Mato Grosso. Ombrophylous open forest (*A*), seasonal deciduous forest (*C*), ombrophylous dense forest (*D*), seasonal semideciduous forest (*F*), pioneer formation (*P*), savanna (*S*), contact zone savanna/steppe-like savanna (*SN*) and contact zone savanna/ombrophylous forest (*SO*)

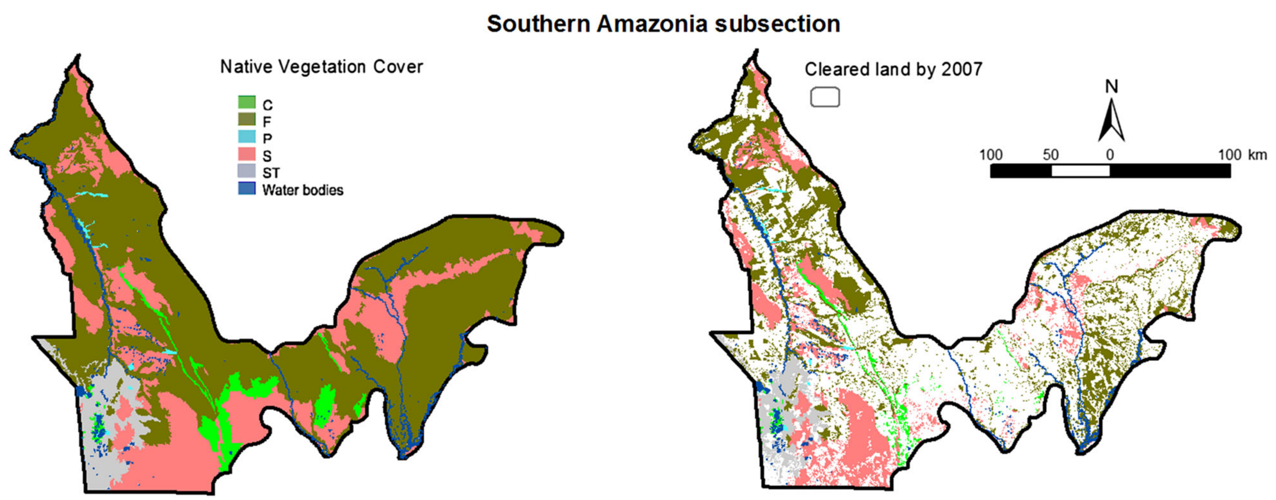

Fig. 3 Native vegetation cover (*left*), remaining vegetation and clearings by 2007 (*right*) in the southern section of the Amazonia Biome in Mato Grosso. Seasonal deciduous forest (*C*), seasonal semideciduous forest (*F*), pioneer formation (*P*), savanna (S) and contact zone savanna/steppe-like savanna (ST)

Native vegetation cleared by 2007 was nearly two times higher in the south compared with the north (59 against 32 %). The significant reduction of native vegetation in the South was followed by exponential increase in the number of patches (Table 1) and in the reduction of their mean size (Table S5). In the North, the patch number increased by 4400 %, while in the south, this rate was of 5300 %. For dominant classes in both areas of Amazonia, forests had the highest patch number increase (85 % of total fragments in the northern, 68 % in the southern part), class area reduction (88 % in the northern, 67 % in the southern part) and mean size reduction (96 times in the North, 162.7 times the South). The mean patch size (MPS) of native vegetation in the North was reduced from 49.4 thousand hectares to only 619 ha in 2007, while in the South, this reduction was from 29.1 thousand hectares to 219 ha. This difference in MPS can be related to the higher proportion of protected areas in the northern part (38.9 % of biome against only 18.4 % in the South). The longer history of land occupation in the southern part of Amazonia also contributed to the greater rate of conversion of NVC located outside protected areas.

Clearings also severely affected minor forest classes inside the forestry matrix in northern and southern Amazonia, by increasing the number of patches and, concomitantly, reducing their total area in the landscape. That is the case for ombrophylous dense forest (D, see also legends of Figs. 2, 3, 4, 5 for abbreviations of the vegetation classes) in northern Amazonia, which originally represented only

5.8 % of the landscape. This vegetation class suffered a reduction of 23.3 % of its original area and experienced an increment of 1300 % in number of patches. This process led to an increment of small patches and could cause their local extinction in this biome (Table 1).

In both northern and southern Amazonia, non-forest classes originally occurred as large disconnected patches inside the forest matrix. In the South, non-forests constituted 32 % of the landscape, while in the North, they were only 11 %. By 2007, however, southern non-forest classes sustained 26 % of all clearings in this region, which reduced their area to 46 %. In the northern part, these rates were 11 and 32 %, respectively.

In northern Amazonia, significant portions of all NVC remnants occurred in protected areas, ranging from 27.2 (SN) to 100 % (C, SO). The remnants of NVC inside protected areas in 2007 corresponded to 54.8 % (15.3 million ha) of the biome, with a very low clearing rate (5.8 %) (Table S3). Therefore, 12.6 million ha remained unprotected in this landscape, but these remnants were predominantly composed by small and discontinuous fragments (Fig. S1). Therefore, in this landscape, larger remaining patches were basically found within Indian Lands and Conservation Units delimited at the northern part of the biome. Legal Reserves protected 21.8 % of the remaining fragments. In spite of the fact that only 6.3 % of NVC remnants were protected in Conservation Units, they are important in conserving larger contiguous patches and also some of the minor forest classes as seasonal deciduous forest and ombrophylous dense forest. The remnants of savanna/ombrophylous forest contact were only found in Indian Lands. On the other hand, LRs were the only protected area type in conserving a part of savanna/seasonal forest contact remnants.

The proportion of NVC remnants inside protected areas in southern Amazonia was 36.8 % (938,068 ha) with only 5.7 % of accumulative clearings (Table S3). Legal Reserves were responsible for protecting 16.3 % of the total remnants in this landscape. As in the northern subsection, however, they showed a highly scattered spatial pattern (Fig. S2). Indian Lands and Conservation Units conserved 12 and 8 %, respectively, of the total area of the native fragments remaining in 2007. Vegetation classes such as savanna/steppe-like savanna contact (ST) occur only in South Amazonia and experienced strong fragmentation. Legal Reserves are a unique type of protected area where the remnants of this NVC could be found. The Pioneer Formation was even more poorly represented in protected areas (10.7 %), but that class occupies frequently flooded floodplains that are less suitable terrains for any use, whereas steppe-like savanna occupies flat alluvial terrains that are being gradually transformed into pastures. Larger and continuous NVC remnants outside of protected areas can be found at the Northwest and West of this landscape, mainly composed by savanna and semi deciduous forest. They remain on rough and/or flooded terrains, which are unsuitable for land use (Fig S2).

Cerrado biome

In the Cerrado, similar major classes of native vegetation were found as in northern Amazonia; however, they had largely different proportions (Table 1; Fig. 4). Forests constituted only 15 % of the biome, surrounded by a

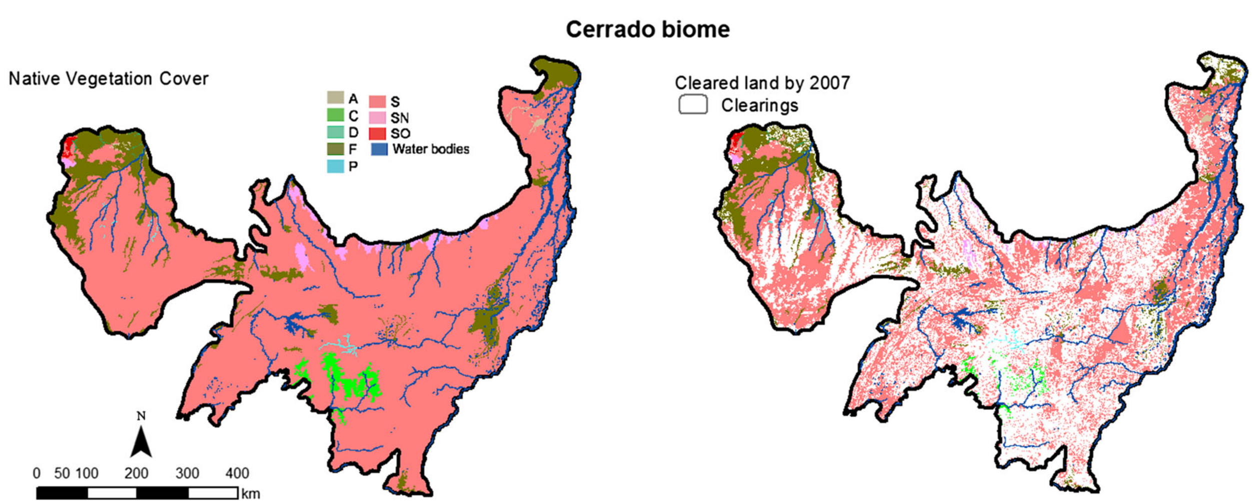

Fig. 4 Native vegetation cover (*left*), remaining vegetation and clearings by 2007 (*right*) in the Cerrado Biome in Mato Grosso. Ombrophylous open forest (*A*), seasonal deciduous forest (*C*), ombrophylous dense forest (*D*), seasonal semideciduous forest (*F*), pioneer formation (*P*), savanna (*S*) and contact zone, Contact zone savanna/ seasonal forest (*SN*); Contact zone savanna/ombrophylous forest (*SO*)

continuous matrix of 85 % of Savanna (S). This class showed the highest rates of patch number increase (53,500 %) among all biomes, while losing 52.1 % of its original area or 16.2 million ha (Table 1). Consequently, the mean patch size of savanna decreased to only 287 ha in 2007, which represented a reduction of 1.100 times compared with the original (Table S5). Forests enclaves suffered 39 % of total reduction, and the patch number increased by of 2000 % when compared to their original cover area. Consequently, most of their remnants are small sized and disconnected (Fig. 4).

The nearly 47 % of remaining NVC in the Cerrado biome was found inside protected areas (PAs) (Table S3). In spite of the protected status, deforestation went on in all types of the PAs and in all biomes. Clearings within PAs in the Cerrado reached 13.9 %—the highest rate among all biomes. The distribution of NVC fragments within PAs corresponded to 26.2 % in Indian Lands, 12.2 % in Legal Reserves and 8.3 % in Conservation Units. Nevertheless, most of the remaining native fragments were outside of PAs. The largest fragments tended to be preferentially clustered within Indian Lands in the west border of biome or in the Northeast (Fig. S3). Remnants of all NVC are represented inside PAs, ranging from 19.3 (A) to 66.9 % (P). The proportion of remnants of Savanna found inside protected areas were 44.1 % (6.5 million ha), from which 11.4 % were within Legal Reserves. Remnants of ombrophylous forest/savanna contact were found only in Indian Lands, which also contributed largely to the protection of the seasonal semideciduous forest (45.8 %), ombrophylous dense forests (43 %) and savannas (23.1 %).

Pantanal biome

This biome was originally composed of a savanna matrix with 83.8 % of Savanna and a small part (1.5 %) of steppe-like savanna (Table 1; Fig. 5). Forests, occurring as islands inside the savanna matrix, constituted 14.7 % of the biome. Land use was more intense close to the biome borders, specifically in the vicinity of larger cities (Cuiabá in North, Corumbá in the East), while the inner parts remained relatively undisturbed, likely due to the hydro-physical conditions of the relief (yearly and multiannual alternating phases of inundation and drought), which are not suitable for land use transformation. Therefore, in the Pantanal, 74.2 % of the Savannas were still intact in 2007. Deciduous forests were the most fragmented NVC in Pantanal. They originally contributed to only 3.3 % of the biome and have since lost 32 % of their original cover. Semideciduous forests suffered a relatively lower area reduction (17.7 %), as most of its remnants occurred inside the regularly flooded terrains of the Pantanal. Steppe-like savanna, which occured in a very inaccessible region, constitutes the unique case of a non-protected NVC that remained unaltered in 2007. Even though, the Pantanal was the biome with the highest proportion of native remnants outside protected areas (72 % or 2.9 million ha), it was also the one with the lowest reduction of the original cover area (24.7 %) in 2007 (Table S3). LRs play a major role in Pantanal, protecting 12.1 % of the remaining fragments, followed by CU (14.8 %). Contrary to the other biomes in our study, Indian Lands had a low contribution to protection of only 1 % of the remaining areas. Large and very

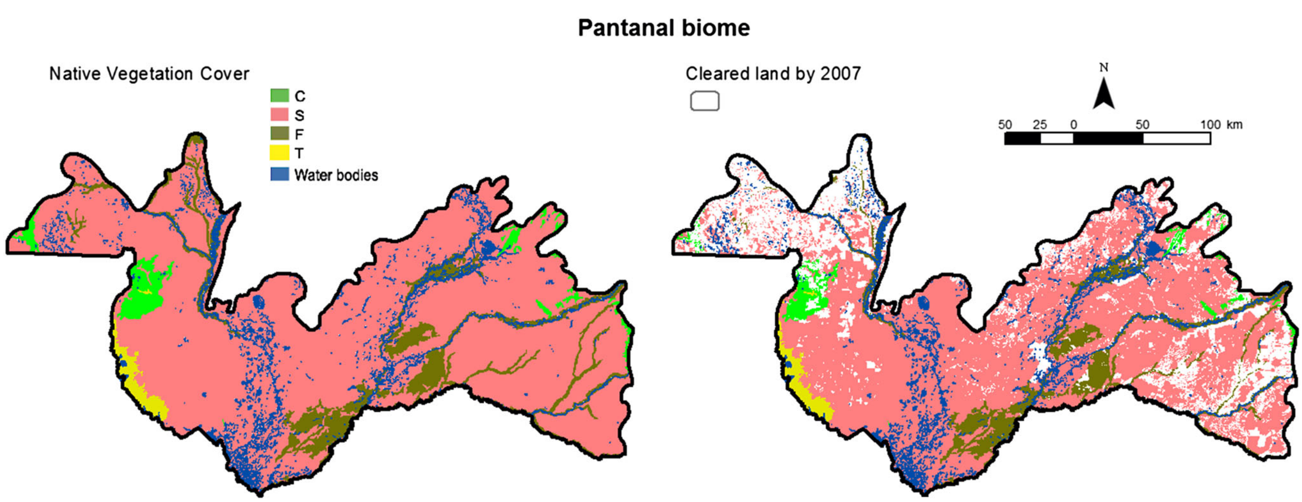

Fig. 5 Native vegetation cover (*left*), remaining vegetation and clearings by 2007 (*right*) in the Pantanal Biome in Mato Grosso. Seasonal deciduous forest (*C*), seasonal semideciduous forest (*F*), savanna (*S*) and steppe-like savanna (*T*)

large Legal Reserve patches (Table S4) tend to be found in the inner part of Pantanal basin as large-sized properties predominate in this part of biome (Fig. 5). Many LRs in the Pantanal were established as compensatory measures for deforestation in the Cerrado biome.

Size of Legal Reserves and their vulnerability

The mean size of LRs ranged from 126.4 ha in the Cerrado to 561.5 ha in northern Amazonia. The variation between biomes can be related to two main factors: the proportion of forest/non-forest classes and the size of rural properties that were registered by 2007. Firstly, the Forest Code prescribes a larger proportion of area to be protected in forests than in savanna vegetation. Therefore, northern Amazonia is the biome with the highest forest/non-forest ratio (7.7) and the greatest average size (561.4 ha) of Legal Reserves. Secondly, larger-sized rural properties have larger LRs even if they have a lower proportion of forests to non-forest. For example, the Pantanal has the lowest forest/non-forest ratio (0.17) but the second largest mean size of LR (487.5 ha).

In all biomes, the number of small-sized (<100 ha) LRs dominated (Northern Amazonia = 78.6 %, Southern Amazonia = 88.6 %, Cerrado = 86.9 % and Pantanal = 78.8 %, (Table S4). Although relatively rare, the biggest patches (>100 ha) contributed the most to the area of LRs in their respective biomes, ranging from 78.6 % in northern to 88.6 % in southern Amazonia.

In our step-wise size reduction scenario, a drastic decrease in patch number and total core area (TCA) of the Legal Reserves occurred in all biomes (Table S5). The most significant effect was observed in Cerrado, where a reduction of only 200 m (1 pixel of our map resolution) would result in a core area reduction of 42.9 and of 73.7 % of LR patches. This is followed by southern Amazonia (37.3 %), northern Amazonia (20.3 %) and the Pantanal (18.3 %). Based on the same 1-pixel reduction algorithm, the reduction of patch number was strongly skewed, indicating a high loss of LR patches ranging from 70.9 % in the Pantanal to 82.3 % in southern Amazonia. These results demonstrate the vulnerability of the LRs to a progressive attrition coming along with the land use. In a scenario of maximal distance of 3200 m (16 pixels), the Legal Reserves would largely disappear in all the biomes (Northern Amazonia = 96.8 %; Southern Amazonia = 99.8 %; Cerrado 99.8 %; Pantanal = 85.9 %) (Table S5).

Discussion

The concept of preserving native forests on rural properties is deeply rooted in Brazilian tradition, as its early references can be found even before 1822, the independence year of Brazil [see (Paixão 2010) for a review]. However, even after the full entitlement of this concept as Legal Reserves in the first Brazilian Forest Code of 1935, and its subsequent reeditions, their conservation has been largely ignored by the land owners in vast portions of the country's rural landscape. One of the most important factors causing this phenomenon was the absence of a country-wide reliable system for registering and monitoring Legal Reserves. This situation has changed in 2001 when the National Cadastre for Rural Properties was developed, which integrates, legal, fiscal, agrarian and environmental information into a geo-referenced database (Paixão 2010). More recently, in the context of the new Brazilian Forest Code in 2012, the National System for Environmental Cadastre of Rural Properties registers all the LRs and Permanent Protected Areas on rural properties in Brazil (CAR 2013). Mato Grosso took an early initiative by registering rural properties and their protected areas since 1999. Despite of the short time-span analyzed here (our study covers the registered datasets of the first 8 years of the system, until 2007), we found evidence that LRs represent an important proportion of preserved areas in the State of Mato Grosso, considering the size of the areas protected and the representativeness of the vegetation classes. The LR patches also play an important role in biome connectivity as a set of stepping stones between intensively used rural areas, large and protected areas, and have the potential to act as seed banks and genetic reservoirs for the recolonization process. Regarding the spatial distribution of the different types of protected areas (Figs. S1, S2, S3, S4), it becomes evident that Legal Reserve patches enlarge or connect existing protected areas, or they even replace them as LRs can often be found in regions not covered by other types of protected areas. Often, LRs protect land of better soil quality than other conservation units do, enabling conservation of different habitat types than those from the State or Federal Reserves (Diniz-Filho et al. 2008). Even minor fragments may have an important function for conservation, depending on their density and proximity to larger patches, as shown in the Atlantic Forest (Ribeiro et al. 2009). Moreover, LRs often border PPAs or larger CU or IL, thereby improving their connectivity and acting as buffer zones of these protected areas. The relationship between LRs and PPAs could not be studied in detail in this study due to the pixel size used. Additional case studies with higher resolution (data not shown here) show that both types are often linked.

A very large number of LR patches were small sized. About 80 % of the LRs registered up until 2007 had a size smaller than 100 ha. The size structure in the State of Mato Grosso is still better than, for example, in the Atlantic Forest, where 83 % of all fragments are <50 ha (Ribeiro et al. 2009). Still, their small size and larger number make them vulnerable to edge effects and land use changes (Table S5). Moreover, many farms have LRs that are smaller than they should be according to the laws. Often, LRs have also been unduly declared as part of other protected areas such as PPAs and State Reserves.

The Cerrado and Amazonia biomes have most of their conserved zones in large protected areas (ILs and CUs), which are mainly located close to their borders, while in the Pantanal, they are preferentially in the central part. The spatial pattern of LR patches could be clearly attributed to the colonization process and the soil/land use relationships. In broad terms, LR patches are generally missing or rare in the most intensively deforested zones in all biomes. Those zones are related to the early nuclei of the colonization, where the land use matrix is more consolidated (e.g., Cerrado and southern Amazonia). LRs are very often set on soils with the least quality for agricultural use in the Cerrado. On the other hand, in most recently occupied areas in northern Amazonia, where occupation is still ongoing, LRs tend to be closer to NVC remnants. There, the logging of the dense forest is more cost intensive than in the Cerrado, LRs very often follow geometrical forms and are situated far away from the roads that bring in the heavy machinery used for deforestation. As the process of LR registration only started in 1999, most of the state territory was already occupied at that time and the potential spaces for LRs had already been transformed into different land uses. If LRs had been registered and conserved since the beginning of the occupation process, a structural pattern similar to those found in most recent parts of the northern Amazonia could have been expected. In the Pantanal (and other remote areas such as the Araguaia river floodplains), LRs are increasingly being placed on farms of landowners that have cleared land in the Cerrado and southern Amazonia to compensate for unduly land use in an economically more productive biome by protecting lands in a less productive one. This practice has recently been sanctioned to be the novel Forest Code of 2012.

The size of LRs was strongly influenced by the higher proportions of protected land adopted by the second version of the Forest Code in 1996. The current version of the Forest Code (BRASIL 2012) maintained these proportions and determined the immediate suspension of all activities in LRs that were illegally cleared after 2008. It also prescribes that the newer LRs must be registered, considering the proximity between them and considering hydrographical features. These measures could contribute to create biological corridors linking LRs and PPAs, mainly located in agricultural zones with better conserved large protected areas (ILs and CUs), which are preferentially located at the borders of the biomes. However, the new Forest Code brings along a series of negative effects on LRs and PPAs. Clearings that occurred until 2008 in LRs inside small to middle properties (<320 ha in Mato Grosso) will no longer be obliged to be recovered, and the new Forest Code similarly grants amnesty of 50–83 % of the permanently protected areas (PPAs) that have previously been cleared in these properties. Irrespective of the size of properties, non-native and commercial perennial species may now be used to recover clearings in LRs until 2008, which means that they will not fulfill their function of maintaining gene flow between native animal and plant populations. The new Forest Code also permits the inclusion of PPAs as part of LRs, which will reduce their mean size. Even more worrying, PPA size in wetlands can now be measured from the lowest water level, which will significantly reduce permanent protection of wetlands defined along rivers. These recent developments show that there is an urgent need to reconnect the fragmented landscapes with native vegetation and thereby to reconcile human needs with biodiversity and ecosystem functions, which are the basis for human existence.

Conclusions

Our study has shown that Legal Reserves have a great importance for conservation of native vegetation in Brazil. They play an important role as stepping stones between or as buffer zone around other preserved areas. However, the study also demonstrated the vulnerability of the LRs, a lack of coherence in their spatial arrangement and even their absence in certain areas. Due to the large scale of our study, we were unable to analyze the state of conservation within LRs. Nor could we study the relationship between LRs and permanently preserved areas (PPAs), which should be done in future studies.

Acknowledgments This study was funded through the projects “Desenvolvimento de metodologia para detecção e mapeamento de áreas degradadas pela mineração e agropecuária em Mato Grosso” by the Secretary of Environment of Mato Grosso State (Contrato n° 071/2008/SEMA) (AS, GAB and MNN), and “Carbon sequestration, biodiversity and social structures in southern Amazonia (CarBioCial, see www.carbiocial.de)” supported by the Brazilian National Counsel of Technological and Scientific Development (CNPq) and the German Ministry of Research and Education (BMBF). We especially thank EAWAG and DAAD (LFR), and the National Institute for Science and Technology in Wetlands (INCT-INAU). We thank Jukka Jokela and Kristy Deiner of EAWAG, Duebendorf, Switzerland, for comments on the manuscript.

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