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Deforestation Trends of Tropical Dry Forests in Central Brazil

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ABSTRACT

Tropical dry forests are the most threatened forest type in the world yet a paucity of research about them stymies development of appropriate conservation actions. The Paranã River Basin has the most significant dry forest formations in the Cerrado biome of central Brazil and is threatened by intense land conversion to pastures and agriculture. We examined changes in Paranã River Basin deforestation rates and fragmentation across three time intervals that covered 31 yr using Landsat imagery. Our results indicated a 66.3 percent decrease in forest extent between 1977 and 2008, with an annual rate of forest cover change of 3.5 percent. Landscape metrics further indicated severe forest loss and fragmentation, resulting in an increase in the number of fragments and reduction in patch sizes. Forest fragments in flatlands have virtually disappeared and the only significant forest remnants are mostly found over limestone outcrops in the eastern part of the basin. If current patterns persist, we project that these forests will likely disappear within 25 yr. These patterns may be reversed with creation of protected areas and involvement of local people to preserve small fragments that can be managed for restoration.

Abstract in Portuguese is available in the online version of this article.

Key words: cerrado; deforestation patterns; forest fragmentation; Paranã River Basin; tropical dry forest.

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Tropical dry forests are broadly defined as a vegetation type dominated by deciduous trees with marked seasonality in precipitation (Murphy & Lugo 1986, Sánchez-Azofeifa *et al.* 2005a, Miles *et al.* 2006, Pennington *et al.* 2006). They are distributed worldwide and frequently associated with savannas (Furley *et al.* 1992, Pennington *et al.* 2000) although determining their original extent remains challenging (Murphy & Lugo 1986, Sánchez-Azofeifa *et al.* 2005a, Pennington *et al.* 2006). Recent estimates indicate that almost 1.6 million km^2 of dry forests exist in the Americas (Portillo-Quintero & Sánchez-Azofeifa 2010).

The Cerrado biome is characterized by a heterogeneous landscape including grasslands, shrublands, gallery forests and dry forests (Silva *et al.* 2006). It is one of the biodiversity hotspots (Myers *et al.* 2000) and holds the greatest plant diversity of any savannah in the world (Brandon *et al.* 2005). The Cerrado biome is severely threatened, with deforestation rates higher than the Amazon rain forest (Klink & Machado 2005). Estimates indicate between 39 and 55 percent of the Cerrado has already been modified (Machado *et al.* 2004, Sano *et al.* 2010), whereas only 2.2 percent is legally protected (Klink & Machado 2005). Dry forests are distributed in large patches along the biome, in plateaus of altitudes between 200 and 1800 m and undergo marked seasonality in precipitation (650–3000 mm) and temperature (16–27°C; Scariot & Sevilha 2005).

Tropical dry forests are among the most threatened and overlooked forest formation in the world (Janzen 1988, Hoekstra *et al.* 2005, Sánchez-Azofeifa *et al.* 2005a, Miles *et al.* 2006). Land conversion to pasture and agriculture are major threats, reflecting a long history of human occupation attracted by fertile soils, flat landscapes, timber extraction and good climatic conditions for agriculture (Maass 1995, Fajardo *et al.* 2005, Sánchez-Azofeifa *et al.* 2005a,b, Miles *et al.* 2006). In Brazil, only 3.9 percent of 273,678 km^2 of dry forests are currently protected (Espírito-Santo *et al.* 2008). The largest enclave of this ecosystem in the Cerrado biome is found within the Paranã River Basin, a region that comprises several endemic species (Silva 1997, Silva & Bates 2002) and is considered of high biological importance (MMA (Ministério do Meio Ambiente) 2002, 2007). Government incentives to promote regional development in the 1970s triggered a rapid increase in human occupation, establishing an economic cycle of timber harvest followed by forest conversion to pastures (Espírito-Santo *et al.* 2009). Charcoal production and limestone mining have also contributed to deforestation as the basin is considered one of the last frontiers in the state of Goiás (Scariot & Sevilha 2005).

A lack of reliable estimates of forest extent and land conversion rates for the tropical dry forests of the Cerrado hinders the establishment of adequate conservation strategies in this region. Therefore, our goal was to describe deforestation trends of dry forests in the Paranã River Basin. We used different fragmentation metrics to track changes in forest cover and to understand current spatial configuration of forest remnants.

METHODS

Study area.—The Paranã River Basin (Fig. S1) is a large depression (59,403 km^2) located between two plateaus in central Brazil,

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representing a transition between the Amazon tropical humid forests and the savannas of the Cerrado and Caatinga biomes in the states of Goiás and Tocantins (Scariot & Sevilha 2005, Carvalho Junior *et al.* 2006). Climate is typical of a tropical savanna (Köppen Aw) characterized by distinct dry (April–September) and rainy (October–March) seasons, with average precipitation of 1200–1300 mm and average annual temperatures ranging from 16 to 21°C (Scariot & Sevilha 2005). Within the basin, a region of fertile Karst soils supports one of the most significant formations of tropical dry forests in Brazil, also known as calcareous forests (Oliveira-Filho & Ratter 2002). Topographic patterns in the region are marked by the predominance of flat areas in the western portion and a north-southbound line of limestone outcrops in the east.

Satellite imagery processing and classification.—To estimate deforestation trends in the Paranã River Basin, we used high resolution satellite imagery from the sensors Landsat 2 Multispectral Scanner (MSS) and Landsat 5 Thematic Mapper (TM), available from the Brazilian Space Agency Instituto Nacional de Pesquisas Espaciais—INPE (http://www.dgi.inpe.br/CDSR/). We selected images acquired near the end of the rainy season (February–April), when deciduous forests still have a dense green canopy that form a noticeable contrast with the cerrado (savannah-like) vegetation in the surroundings. Cloud cover is usually sparse or absent during this time of year. We used 15 scenes spanning 31 yr and divided them into three intervals using years 1977, 1993/1994 and 2008 (Table S1). Cloud-free images covering our study region were unavailable for our preferred dates, thus a composite of scenes from 1993 and 1994 was necessary for analysis of the second interval. All imagery was pre-processed in ERDAS IMAGINE 8.7 (Leica Geosystems GIS and Mapping, LLC, U.S.A.), following the standard operating methods described in Kennedy *et al.* (2007) that include imagery selection and referencing, geometric correction with cubic convolution to output cell size of 25 m in the polynomial model and projection to datum WGS 84. Next, we performed unsupervised classification of each image using 30 classes, 40 iterations and a convergence threshold of 0.99. Last, we performed analysis with visual interpretation between each original and corresponding classified image to a post-classification scheme, producing binary 'forest' and 'non-forest' maps for each time interval. Binary classification systems are simple and can help reduce potential errors due to imagery quality (Gergel 2007). Additionally, a binary system is likely to perform best for accurate change detection in highly contrasting forest and open (natural or human originated) landscapes as found in our study area.

Ground control points and map validation.—We carried out an extensive search for dry forest fragments in the region, collecting ground control points at least one km apart to validate the resulting maps. We recorded information about land cover type (dry forest, riparian forest, savanna, pasture, and agriculture) from 269 sites visited in 2008 using a GPSMAP 76S GPS (Garmin Intl. Inc., U.S.A.). Overall classification accuracy and Kappa statistics (a measure of agreement based on the difference between classified and reference data; Congalton & Green 2009) were then estimated only for 2008, after selecting 211 sites following a binomial distribution sampling scheme aimed at a minimum overall accuracy of 85 percent (Foody 2002) with a 95% confidence level (Czaplewski 2003, Congalton & Green 2009).

Geographic boundaries and deforestation analysis.—We built one map using ArcGIS v.9.2 (ESRI Inc., U.S.A.) for each time interval by combining the corresponding five classified images and aggregating pixels to conduct analyses at a 1-ha minimum mapping unit using the basin's boundaries as the extent. Additionally, we created a mask polygon corresponding to the distribution limits of the dry forest within the basin to be used as the boundary for the deforestation analysis. This polygon was delimited by hand after visual interpretation of the original imagery and closely matched the limits of dry forests in the region proposed by Carvalho Junior *et al.* (2006) based on precipitation parameters and data derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor.

Landscape metrics were calculated to compute spatiotemporal changes in the forest cover using Fragstats 3.3 (McGarigal *et al.* 2002) at the patch and class level and by applying the neighborhood rule of eight cells. Selection of metrics describing patterns of habitat loss and fragmentation followed recommendations of Neel *et al.* (2004) and Gergel (2007): (1) total area; (2) percentage of landscape (PLAND); (3) number of patches; (4) patch area (mean and SD); (5) largest patch index (LPI); and (6) clumpiness index (CLUMPY). Detailed information about these metrics and formulas are found in McGarigal *et al.* (2002) but briefly, total area and percentage of landscape are simple indices related to the extent of the target class, thus any change in land cover between two intervals are depicted by these metrics. Number of patches is a measure of the extent of fragmentation of the patch type, therefore an increase in number of patches is likely due to increased fragmention levels. Patch area is among the most important metrics of the landscape as it is not only related to extent but also provides useful information about fragmentation and habitat loss. Largest patch index is a measure of dominance that indicates the percentage of total landscape comprised by the largest patch. Clumpiness index is a measure of class aggregation that ranges from −1 when the target class is maximally disaggregated to +1 otherwise, and usually is a robust fragmentation metric, given its independence to variations in class area (Neel *et al.* 2004, Gergel 2007). Finally, we calculated estimates of annual forest cover change (FCC) using an adapted formula of Puyravaud (2003) to express results in percentage, as follows: $FCC(\%) = (1/t_2 - t_1) \times \ln(A_2/A_1) \times 100$; where $(t_2 - t_1)$ is the period analyzed, and A_1 and A_2 the forest cover at time t_1 and t_2, respectively.

RESULTS

Classification accuracy.—Overall accuracy of the 2008 image classification was estimated at 89.6 percent with 189 points

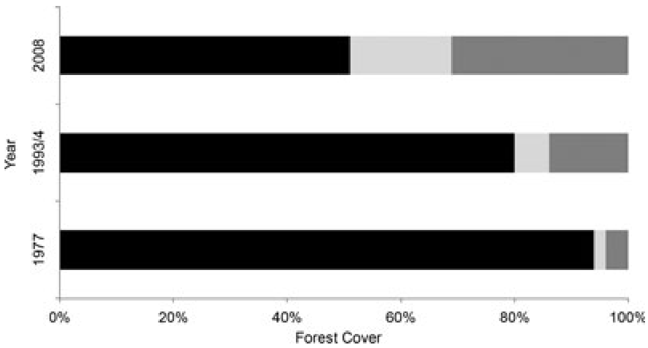

FIGURE 1. Percentage of dry forest in fragments of different sizes (black ≥10 km^2, light gray = 2.6–10 km^2; dark gray = ≤ 2.5 km^2) in the Paranã River Basin of Brazil.

correctly classified and Kappa statistic of 0.78. It was not possible to assess accuracy for time 1 (1977) and time 2 (1993/94), given the absence of corresponding ground control points. We assume, however, that these intervals would have sufficient accuracy to support our results. This assumption is based on our long-term knowledge of the area, imagery quality, and use of same criteria for image classification, even considering the set of Landsat MSS imagery to be of lower resolution than Landsat TM.

FOREST LOSS AND FRAGMENTATION.—Over 31 yr, there was a 66.3 percent reduction in forest cover within the polygon of dry forests in the Paranã River Basin (Fig. S2A–C). The annual forest cover change (FCC) was estimated at 3.5 percent. Reduction in forest cover was estimated at 35.7 percent between 1977–1993/94 and at 47.6 percent between 1993/94–2008. The estimated annual forest cover change during the first and second time periods was 2.6 percent and 4.6 percent decrease, respectively. Visual interpretation of the results further suggested an asymmetrical trend in deforestation, showing more aggregations of forest remnants towards the eastern limits of the basin over the years (Fig. S2A–C). In the Paranã Valley, deforestation rates were slightly higher than in the dry forest polygon, with reduction of forest cover estimated at 38.3 percent between 1977–1993/94 and 54.4 percent between 1993/94–2008. Overall loss in forest cover for the valley was estimated at 71.9 percent and annual forest cover change estimates suggested a 2.8 percent and 5.6 percent decrease, for intervals 1 and 2, respectively.

Landscape metrics also indicated similar results of extensive forest loss and increased forest fragmentation in the dry forest polygon (Table 1). Total forest cover area decreased from 12,919 to 8311 km^2 and then to 4352 km^2, respectively, between the first and second intervals. The percentage of the study landscape comprised of dry forest also decreased within the basin from a 21.7 to seven percent over the 31 yr period (Table 1). Patch number increased from 4746 to 9691 (104%) between the first and last time intervals, while mean patch size decreased from 2.72 to 0.44 km^2 (84%) in the same period. Likewise, the largest patch index experienced a sharp reduction of more than 97 percent over the years while clumpiness decreased only 4.1 percent. The distribution of fragments per size indicated an increase in all categories across time, but only fragments larger than 10 km^2 indicated considerable reduction (94.8%) in mean size ranging from 762.49 to 38.96 km^2 (Table 2). Further, large fragments (>10 km^2) decreased in forest extent from approximately 94 percent in 1977 to 51 percent in 2008. Intermediate (2.6–10 km^2) and small (≤ 2.5 km^2) size fragments increased drastically, from six to 49 percent when grouped (Fig. 1).

TABLE 1. *Landscape metrics of forest class for deforestation analyses of the dry forest polygon in the Paranã River Basin, central Brazil.*

Year	Total Forest Area (km^2)	PLAND[a]	N Patches	Patch Area (km^2) Mean	Patch Area (km^2) SD	LPI	CLUMPY
1977	12919	21.7	4746	2.72	172.10	59.0	0.8072
1993/94	8311	14	8074	1.03	45.62	20.1	0.7897
2008	4352	7.3	9691	0.44	4.99	1.7	0.7738

[a]Relative to the Paranã River Basin (area = 59,344 km^2).

TABLE 2. *Number of patches per category of size (in km^2) with respective mean patch size and standard deviation (SD) in three intervals over 31 years in the dry-forest polygon in the Paranã River Basin, Brazil.*

Size Class	1977 N Patches	1977 Mean Patch Size (SD)	1993/94 N Patches	1993/94 Mean Patch Size (SD)	2008 N Patches	2008 Mean Patch Size (SD)
≤ 2.5	4686	0.10 (0.24)	7914	0.14 (0.30)	9474	0.14 (0.29)
2.6–10	44	6.05 (0.72)	111	6.26 (0.77)	160	6.04 (0.64)
>10	16	762.49 (2959)	49	136.10 (575.61)	57	38.96 (52.05)
Total	4746		8074		9691	

DISCUSSION

This study brings a unique perspective about the deforestation of tropical dry forests in the Cerrado biome of Brazil over a large temporal (31 yr) and spatial (over 59,000 km^2) scales. Our most recent estimate (year 2008) showed that the Paranã River Basin comprises 4352 km^2 of this threatened ecosystem. Because of the fine scale used in our study, we consider that our results are likely the best approximation to the actual extent of dry forest within this region.

ACCURACY ASSESSMENT AND SOURCES OF ERROR.—Our classification accuracy was above the minimum acceptable levels of 85 percent for overall accuracy and 70 percent for individual classes (Foody 2002). Potential sources of error and limitations commonly incorporated during imagery processing and classification (Langford *et al.* 2006), however, need to be addressed. A binary classification system ('forest' and 'non-forest') was used to reduce misclassification error that may occur when several forest classes are used. This approach is a simplification of the actual landscape used in other similar studies (Gasparri & Grau 2009, Songer *et al.* 2009, Whitehurst *et al.* 2009, Portillo-Quintero & Sánchez-Azofeifa 2010) and helped to improve our classification accuracy, as forest cover contrasts strongly from other land cover types. We consider errors due to the use of scenes from subsequent years (1993 and 1994; Table S1) for the second interval composite to be negligible, particularly when accounting for an annual forest cover change of 3.5 percent over a period of 31 yr. Finally, the lower resolution of Landsat MSS imagery contrasting with Landsat TM was minimized by selecting only superior quality cloud-free MSS scenes available at the INPE's database and also by applying a binary classification scheme.

DEFORESTATION ANALYSIS.—Global estimates of deforestation indicate that nearly 48.5 percent of the tropical dry forests have been lost to other land cover types (Hoekstra *et al.* 2005) while in the Americas estimates of dry forest loss range between 60 to 72 percent (Portillo-Quintero & Sánchez-Azofeifa 2010). The forest cover change rate found in this study (3.5 percent annually) was comparable to deforestation rates reported from other dry forests: 1.4 percent in Mexico (Trejo & Dirzo 2000); 2.1 percent in Costa Rica (Steininger *et al.* 2001); 1.1 to 2.6 percent in Venezuela (Fajardo *et al.* 2005); 0.83 percent (Gasparri & Grau 2009) to 5 percent (Boletta *et al.* 2006) in Argentina; and 1.8 percent in Myanmar (Songer *et al.* 2009). In a sample area of nearly 180 ha, located in flatlands of the Paranã River Basin, Andahur (2001) found an annual forest cover decrease of 6.6 percent between 1990 and 1999. Nevertheless, caution is warranted when comparing deforestation rates as, except for our study and Boletta *et al.* (2006), all other studies have used different formulae than the FCC adapted from Puyravaud (2003).

Our results demonstrated that high levels of forest fragmentation had greatly impacted the region based on substantial decreases of total forest area, percentage of forest landscape, mean forest patch area and largest forest patch index. Similarly, the increase in the number of patches indicated considerable fragmentation (Table 1). The clumpiness index was the only metric to show a small reduction between first and last intervals (4.1%), but still suggests that fragmentation has occurred. Because clumpiness is a measure of aggregation, we believe it has mostly captured fragmentation in forest areas clustered with limestone outcrops in the eastern part of the study area. These outcrops form a linear north-southbound chain of exposed rocks and cave systems that is still reasonably aggregated (Table 1).

Forest fragmentation observed in our study area was consistent with studies from other regions with tropical dry forests. Portillo-Quintero and Sánchez-Azofeifa (2010) found that within the Cerrado biome, more than 60 percent of dry forest fragments are larger than 10 km^2. They argued that this pattern was also found in other studies (Fajardo *et al.* 2005, Pennington *et al.* 2006) and is more related to soil fertility and moisture gradients rather than human activities. We found a similar result (51 percent of fragments larger than 10 km^2) in the Paranã River Basin but this pattern seems to be a consequence of human actions. This discrepancy is likely due to differences in spatial scales between the two studies, as we have used a minimum mapping unit of one hectare versus 100 hectares in their study. Yet, this finding is relevant because it shows the importance of regional scale assessments of land cover change for detecting distinct patterns of forest distribution and fragmentation that may be useful for landscape and conservation planning.

Our analysis indicates a drastic reduction in size of large forest fragments and the increase of forest fragments of intermediate to small sizes (Table 2). In a fragmented landscape, larger fragments are usually better suited to sustain more species and maintain ecosystem functions less affected by fragmentation (Laurance *et al.* 2002). As the tropical dry forests of the Cerrado represent a relatively uniform ecological unit amid a heterogeneous landscape, protecting a mosaic of large fragments is more likely to prevent further loss of biodiversity and ecosystem functions.

Based on the proportion of forest removed during the 31 yr period (66.3%) and the remaining extent of forest (4352 km^2) estimated in this study, we predict that tropical dry forests in the Paranã River Basin may no longer exist within 20–25 yr if current trends persist. Present land use practices tend to replace forest cover with pastures for livestock, particularly along the Paranã Valley (Scariot & Sevilha 2005, Espírito-Santo *et al.* 2009). Between 2002 and 2007, annual deforestation rate in the valley was estimated at 2.3 percent while livestock population has grown 7.4 percent annually in the same period (SEPIN (Superintendência de Estatística, Pesquisa e Informação) 2011). Furthermore, governmental regulations prohibiting deforestation of sensitive areas (*e.g.,* riparian zones) have not been followed by many landowners (Sampaio 2006). Forest conversion in the basin seems to be limited only by the topographical barrier represented by the limestone outcrops (Fig. S3) as we noticed that most forest fragments were found surrounding large blocks of exposed rock. This rugged landscape gradually increases towards the eastern limits of the basin and likely explains the eastward aggregation of forest fragments observed in our analyses (Fig. S2A–C).

Contrasting with the western region, this portion contains a high number of subsistence farms (<100 ha) characterized by a mosaic of pastures amid outcrops and ravines with forest (Scariot & Sevilha 2005, Espírito-Santo *et al.* 2009). Although forest fragments associated with outcrops may represent potential areas for the conservation of dry forests, some studies have shown that these forests have different floristic and physiognomic characteristics (Pedralli 1997) with lower species richness when compared to forests of flat areas (Silva & Scariot 2003, Scariot & Sevilha 2005).

Legal protection of tropical dry forests in Brazil was just recently implemented (Federal Law 11428/06 and Federal Decree 6660/08) and several other measures regarding modifications in land use policies have been discussed (Espírito-Santo *et al.* 2009). On a regional scale, the Paranã River Basin was classified as high priority area for biodiversity conservation (MMA [Ministério do Meio Ambiente] 2007), but it is unclear how this designation will be reconciled with economic development policies still in place (Andahur & Chaves 2003). Espírito-Santo *et al.* (2009) have shown that less than 4300 km^2 (7.2%) of the Cerrado in the Paranã River Basin are currently protected. The Terra Ronca State Park is the largest reserve (570 km^2, which 50 percent is represented by dry forests) yet to be fully implemented. The effectiveness of conservation measures in other protected areas of less restrictive categories that allow some use of natural resources and human occupation (*e.g.,* IUCN category VI, Espírito-Santo *et al.* 2009) may be less assured. While new protection areas have already been proposed within the basin (F. Olmos, pers. comm.), our results suggest further investigation of large forest fragments (<10 km^2) in the municipalities of Aurora, Novo Alegre and Combinado in the state of Tocantins, and Divinópolis and São Domingos in the state of Goiás.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

FIGURE S1. Location of the Paranã River Basin and the Paranã Valley in central Brazil.

FIGURE S2. Forest extent using a binary classification in three intervals (A–C) over 31 yr for the Paranã River Basin, Brazil.

FIGURE S3. Pattern of deforestation showing pastures and croplands limited by the presence of limestone outcrops in the Paranã River Basin of Brazil.

TABLE S1. *Landsat images of the Tropical Dry Forest in central Brazil including path/row numbers and acquisition date.*

LITERATURE CITED

Andahur, J. P. 2001. Florestas e Questões de Gestão Ambiental na Bacia do Rio Paranã. MSc Dissertation, Universidade de Brasília, Brasília, DF, Brazil.

Andahur, J. P., and H. M. L. Chaves. 2003. Zoneamento Agroecológico e Florestas Deciduais na Bacia do Rio Paranã. Brasil Florestal 22: 35–39.

Boletta, P. E., A. C. Ravelo, A. M. Planchuelo, and M. Grilli. 2006. Assessing deforestation in the Argentine Chaco. For. Ecol. Manage. 228: 108–114.

Brandon, K., G. A. B. da Fonseca, A. B. Rylands, and J. M. C. da Silva. 2005. Special section: Brazilian conservation: Challenges and opportunities. Conserv. Biol. 19: 595–600.

Carvalho Junior, O. A., P. M. Hermuche, and R. F. Guimarães, 2006. Identificação Regional da Floresta Estacional Decidual na Bacia do Rio Paranã a partir da Análise Multitemporal de Imagens MODIS. Revista Brasileira de Geofísica 24: 319–332.

Congalton, R. G., and K. Green. 2009. Assessing the accuracy of remotely sensed data: Principles and practices. CRC Press, Boca Raton, Florida.

Czaplewski, R. L. 2003. Accuracy assessment of maps of forest condition: Statistical design and methodological considerations. In M. A. Wulder, and S. E. Franklin (Eds.). Remote sensing of forest environments. concepts and case studies, pp. 115–140. Kluwer Academic Publisher, Massachussets, Boston.

Espírito-Santo, M. R. M., M. Fagundes, A. C. Sevilha, A. Scariot, A. Sánchez-Azofeifa, S. E. Noronha, and G. W. Fernandes. 2008. Florestas estacionais deciduais brasileiras: Distribuição e estado de conservação. MG Biota 1: 5–13.

Espírito-Santo, M. M., A. C. Sevilha, F. C. Anaya, R. Barbosa, G. W. Fernandes, G. A. Sánchez-Azofeifa, A. Scariot, S. E. Noronha, and C. A. Sampaio. 2009. Sustainability of tropical dry forests: Two case studies in southeastern and central Brazil. For. Ecol. Manage. 258: 922–930.

Fajardo, L., V. Gonzalez, J. M. Nassar, P. Lacabana, C. A. Portillo-Quintero, F. Carrasquel, and J. P. Rodriguez. 2005. Tropical dry forests of Venezuela: Characterization and current conservation status. Biotropica 37: 531–546.

Foody, G. M.. 2002. Status of land cover classification accuracy assessment. Remote Sens. Environ. 80: 185–201.

Furley, P. A., J. Proctor, and J. A. Ratter. 1992. Nature and dynamics of forest-savanna boundaries. Chapman and Hall, London.

Gasparri, N. I., and H. R. Grau. 2009. Deforestation and fragmentation of Chaco dry forest in NW Argentina (1972–2007). For. Ecol. Manage. 258: 913–921.

Gergel, S. E. 2007. New directions in landscape pattern analysis and linkages with remote sensing. In M. A. Wulder, and S. E. Franklin (Eds.). Understanding forest disturbance and spatial pattern, pp. 173–208. CRC Press, Boca Raton, Florida.

HOEKSTRA, J. M., T. M. BOUCHER, T. H. RICKETTS, AND C. ROBERTS. 2005. Confronting a biome crisis: Global disparities of habitat loss and protection. Ecol. Lett. 8: 23–29.

JANZEN, D. H. 1988. Tropical dry forest: The most endangered major tropical ecosystem. In E. O. Wilson (Ed.). Biodiversity, pp. 130–137, National Academy Press, Washington, D.C.

KENNEDY, R. E., W. B. COHEN, A. A. KIRSCHBAUM, AND E. HAUNREITER. 2007. Protocol for Landsat-based monitoring of landscape dynamics at North Coast and Cascades Network Parks: U.S. Geological Survey Techniques and Methods 2–G1. U. S. Geological Survey, Reston, VA.

KLINK, C. A., AND R. B. MACHADO. 2005. Conservation of the Brazilian Cerrado. Conserv. Biol. 19: 707–713.

LANGFORD, W. T., S. E. GERGEL, T. G. DIETTERICH, AND W. B. COHEN. 2006. Map misclassification can cause large errors in landscape pattern indices: Examples from habitat fragmentation. Ecosystems 9: 474–488.

LAURANCE, W. F., T. E. LOVEJOY, H. L. VASCONCELOS, E. M. BRUNA, R. K. DIDHAM, P. C. STOUFFER, C. GASCON, R. O. BIERREGAARD, S. O. LAURANCE, AND E. SAMPAIO. 2002. Ecosystem decay of Amazonian Forest Fragments: A 22-year investigation. Conserv. Biol. 16: 605–618.

MAASS, J. M. 1995. Conversion of tropical dry forest to pasture and agriculture. In S. H. Bullock, H. A. Mooney and E. Medina (Eds.). Seasonally dry tropical forests, pp. 399–422. Cambridge University Press, Cambridge.

MACHADO, R. B., M. B. R. NETO, P. G. P. PEREIRA, E. F. CALDAS, D. A. GONçALVES, N. S. SANTOS, K. TABOR, AND M. STEININGER. 2004. Estimativas de perda da área do Cerrado brasileiro. Unpublished report. Conservação Internacional, Brasília.

MCGARIGAL, K., S. A. CUSHMAN, M. C. NEEL, AND E. ENE. 2002. FRAGSTATS: Spatial pattern analysis program for categorical maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at www.umass.edu/landeco/research/fragstats/fragstats.html (accessed 12 December 2010).

MILES, L., A. C. NEWTON, R. S. DEFRIES, C. RAVILIOUS, I. MAY, S. BLYTH, V. KAPOS, AND J. E. GORDON. 2006. A global overview of the conservation status of tropical dry forests. J. Biogeogr. 33: 491–505.

MMA (Ministério do Meio Ambiente). 2002. Biodiversidade Brasileira - Avaliação e identificação de áreas prioritárias para a conservação, utilização sustentável e repartição de benefícios da biodiversidade brasileira. Ministério do Meio Ambiente, Brasília, Brasil.

MMA (Ministério do Meio Ambiente). 2007. Áreas prioritárias para a conservação, uso sustentável e repartição de benefícios da biodiversidade brasileira: Atualização. Ministério do Meio Ambiente, Brasília, Brasil.

MURPHY, P. G., AND A. E. LUGO. 1986. Ecology of tropical dry forest. Annu. Rev. Ecol. Syst. 17: 67–88.

MYERS, N., R. A. MITTERMEIER, C. G. MITTERMEIER, G. A. B. da FONSECA, AND J. KENT. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853–858.

NEEL, M. C., K. MCGARIGAL AND S. A. CUSHMAN. 2004. Behavior of class-level landscape metrics across gradients of class aggregation and area. Landscape Ecol. 19: 435–455.

OLIVEIRA-FILHO, A. T., AND J. A. RATTER. 2002. Vegetation physiognomies and woody flora of the cerrado biome. In P. S. Oliveira, and R. J. Marquis (Eds.). The Cerrados of Brazil: Ecology and natural history of a neotropical savanna, pp. 91–120, Columbia University Press, New York.

PEDRALLI, G.. 1997. Florestas secas sobre afloramentos de calcário em Minas Gerais: Florística e fisionomia. Bios 5: 81–88.

PENNINGTON, R. T., G. P. LEWIS, AND J. A. RATTER. 2006. Neotropical Savannas and seasonally dry forests: Plant diversity, biogeography and conservation. CRC Press, Boca Raton, New York.

PENNINGTON, R. T., D. E. PRADO, AND C. A. PENDRY. 2000. Neotropical seasonally dry forests and Quaternary vegetation changes. J. Biogeogr. 27: 261–273.

PORTILLO-QUINTERO, C. A., AND G. A. SÁNCHEZ-AZOFEIFA. 2010. Extent and conservation of tropical dry forests in the Americas. Biol. Conserv. 143: 144–155.

PUYRAVAUD, J.-P. 2003. Standardizing the calculation of the annual rate of deforestation. For. Ecol. Manage. 177: 593–596.

SAMPAIO, A. B. 2006. Restauração de florestas estacionais deciduais de terrenos planos no norte do vão do Rio Paranã, GO. PhD Dissertation, Universidade de Brasília, Brasília, Brazil.

SÁNCHEZ-AZOFEIFA, G. A., M. E. R. KALACSKA, M. QUESADA, J. C. CALVO-ALVARADO, J. M. NASSAR, AND J. P. RODRÍGUEZ. 2005b. Need for integrated research for a suitable future in tropical dry forests. Conserv. Biol. 19: 285–286.

SÁNCHEZ-AZOFEIFA, G. A., M. QUESADA, J. P. RODRIGUEZ, J. M. NASSAR, K. E. STONER, A. CASTILLO, T. GARVIN, E. L. ZENT, J. C. CALVO-ALVARADO, M. E. R. KALACSKA, L. FAJARDO, J. A. GAMON, AND P. CUEVAS-REYES. 2005a. Research priorities for neotropical dry forests. Biotropica 37: 477–485.

SANO, E. E., R. ROSA, J. L. S. BRITO, AND L. G. FERREIRA. 2010. Land cover mapping of the tropical savanna region in Brazil. Environ. Monit. Assess. 166: 113–124.

SCARIOT, A. O., AND A. C. SEVILHA. 2005. Biodiversidade, Estrutura e Conservação das Florestas Estacionais Deciduais no Cerrado. In A. O. Scariot, J. C. Souza-Silva, and J. M. Felfili (Eds.). Cerrado: Ecologia, Biodiversidade e Conservação, pp. 121–139, Ministério do Meio Ambiente (MMA), Brasília, Brasil.

SEPIN (Superintendência de Estatística, Pesquisa e Informação). 2011. Estatísticas Básicas – Pecuária. Governo do Estado de Goiás. Available at http://www.seplan.go.gov.br/sepin/index.asp, (accessed 28 June 2011).

SILVA, J. M. C.. 1997. Endemic bird species and conservation in the Cerrado region, South America. Biodiversity and Conserv. 6: 435–450.

SILVA, J. M. C., AND J. M. BATES. 2002. Biogeographic patterns and conservation in the South American Cerrado: A tropical Savanna hotspot. Bioscience 52: 225–233.

SILVA, J. F., M. R. FARINAS, J. M. FELFILI, AND C. A. KLINK. 2006. Spatial heterogeneity, land use and conservation in the cerrado region of Brazil. J. Biogeography 33: 536–548.

SILVA, L. A., AND A. SCARIOT. 2003. Composição florística e estrutura da comunidade arbórea em uma floresta estacional decidual em afloramento calcário (Fazenda São José, São Domingos, GO, bacia do rio Paranã). Acta Bot. Bras. 17: 305–313.

SONGER, M., A. MYINT, B. SENIOR, R. DEFRIES, AND P. LEIMGRUBER. 2009. Spatial and temporal deforestation dynamics in protected and unprotected dry forests: A case study from Myanmar (Burma). Biodiversity Conserv. 18: 1001–1018.

STEININGER, M. K., C. J. TUCKER, P. ERSTS, T. J. KILLEEN, Z. VILLEGAS, AND S. B. HECHT. 2001. Clearance and fragmentation of tropical deciduous forest in the Tierras Bajas, Santa Cruz. Bolivia. Conserv. Biol. 15: 856–866.

TREJO, I., AND R. DIRZO. 2000. Deforestation of seasonally dry tropical forest: A national and local analysis in Mexico. Biol. Conserv. 94: 133–142.

WHITEHURST, A. S., J. O. SEXTON, AND L. DOLLAR. 2009. Land cover change in western Madagascar's dry deciduous forests: A comparison of forest changes in and around Kirindy Mite National Park. Oryx 43: 275–283.