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Modeling tree cover changes in a pasture-dominated landscape by adopting silvopastoral practices in a dry forest region in Central Brazil

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Abstract Pastures are a major soil cover in Central Brazil, especially in rich soils previously occupied by dry forests. We simulated a scenario in which the wooden fences in Paranã Valley are replaced by live fences and isolated trees are left in the pasture fields, and we verified changing in tree cover by adding trees and avoiding logging for wooden fences. The simulation involved the analysis of a 20-year historic series of LANDSAT satellite images to determine the average time of pasture renewal. The average amount of wooden fences produced per hectare of local forest was estimated based on the literature and field data. The high spatial-resolution satellite images available in the Google Earth™ program were analyzed to estimate the total length of the fences and the average and maximum number of isolated trees per hectare found in the pastures of the region. The results showed that pasture renewal happens every 8.1 years. It is possible to produce an average of 1,472 stakes per hectare of forest. In the study area, we estimated the existence of an average of 842 km of wooden fences and 3.9 isolated trees per hectare of pasture (maximum = 48 isolated trees). The results of the simulation showed that the adoption of live fences can increase the crown coverage up to 7.5 % or even up to 14.3 % if all of the pasturelands are managed to have live fences and farmers begin to adopt cover-development practices, such as keeping an average of 48 isolated trees per hectare of pasture.

Keywords Landscape modeling · Tropical pastures · Sustainable meat production · Agroforestry system

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Introduction

Pastures dominate 25 % of terrestrial ecosystems and 2/3 of agricultural areas (Lambin et al. 2003). The expansion of pastures is currently responsible for 2/3 of the loss of forest cover in Latin America (Wassenaar et al. 2007), and these lands occupy 26.5 % of the Brazilian tropical savanna (Sano et al. 2008). Because of the role of pasturelands in forest clear-cutting processes and in the increasing impact on the environment, some institutions concerned with environmental conservation have proposed specific sustainable practices (FAO 2006; SAN 2010). One such practice is an increase in tree density in pasture-related fields, which can be achieved, for example, using live fences instead of wooden fences or by increasing the number of isolated trees in pasture fields (León and Harvey 2006; Harvey et al. 2008; RAS 2010).

Live fences consist of rows of evergreen trees sustaining wires to separate farms, pasture fields, or other land-use classes. The use of live fences is routine in some countries, particularly in southern Mexico and Central America (Budowski 1998; Zahawi 2005), Colombia, Venezuela, and South Ecuador (Budowski 1998), East Africa (Duvall 2009), and East India (Choudhury et al. 2005). Furthermore, live fences are of particular importance in restoring degraded vegetation (Harvey et al. 2003, 2008).

The ecological benefits of live fences include a reduction of selective logging for wooden fences, an increase in carbon sequestration from the atmosphere, and an increase in landscape connectivity (Ávila 2003; Villanueva et al. 2005, 2008). In addition, there may be significant increases in wildlife diversity, mainly for birds (Gabriel and Pizo 2005; Harvey et al. 2005), and a potential increase in the genetic flow of fauna and flora (Estrada et al. 2000). Saving individual trees in pasture fields also contributes to improvements in the ecological functioning and animal production. The Food and Agriculture Organization of the United Nations—FAO (2006)—reported increases in soil water infiltration and pasture productivity and reductions of soil loss by erosion. Other studies also noted an increase in tree species (Guevara et al. 2005) and a better functioning of these areas as stepping-stones for birds and bats (Esquivel et al. 2003; Guevara et al. 2005; Ibrahim et al. 2005). Individual trees can also function as starting points for forest regeneration in cases in which there is an abandonment of agricultural activities (Guevara et al. 2005; Berens et al. 2008; Schlawin and Zahawi 2008).

The use of live fences in Brazil is still incipient (Nascimento et al. 2009), and the lack of knowledge regarding the most appropriate tree species and the economic and environmental benefits is the major reason for this situation. A region in Brazil suitable for implementing large-scale living fences is the Paranã Valley, located in the Northeastern Goiás State (IBGE 2005). Selective logging for production of wooden fences is common in this region and is compromising the remaining fragments of decidual forests (Scariot and Sevilha 2005; Felfili et al. 2007). Furthermore, decidual forests have high resprouting ability (Vieira and Scariot 2006). Many trees persist in areas already converted into pastures for a long time (Vieira et al. 2006; Sampaio et al. 2007), making farmers renew their pastures from time to time. Knowing and using this potential to establishing silvopastoral systems is worthwhile. The objective of this study is to (i) estimate the frequency of pasture renovation and (ii) simulate a scenario in which the wooden fences in Paranã Valley are replaced by live fences and isolated trees are left in the pasture fields. Based on this modeling approach, we analyzed the potential increase of crown coverage and potential decrease of timber exploration in this region.

Materials and methods

Study areas

We selected three 10-km × 15-km study areas located in Paranã Valley, in the northeastern part of Goiás State (Fig. 1). The plots are located in the municipalities of São Domingos, Guarani de Goiás, and Posse. The criteria for site selection were as follows: a flat topography; the presence of limestone, as the deciduous forests in Central Brazil are often associated with limestone soils (BRASIL 1982); and the existence of large fragments of natural vegetation. The land cover in this region is represented by the Cerrado physiognomies (grasslands, shrublands, and forestlands, including deciduous forests; Silva and Scariot 2004; Nascimento et al. 2007) and by cultivated pastures.

Using the Google Earth™ computer program, we selected SPOT satellite images with 10- and 2.5-m spatial resolutions and overpasses from 2009 to 2010 for the three selected areas. The images were mosaicked and georeferenced using a set of 40 GPS-based control points obtained from a field campaign conducted in August and September 2010. The images were projected onto the Universal Transverse Mercator (UTM) system (zone, 23S; datum, WGS84). The root mean square error was lower than 0.5 pixels.

The mosaics were processed using image segmentation (Sano et al. 2008) of the growing region. The values of similarity and area were set to 40 and 30,

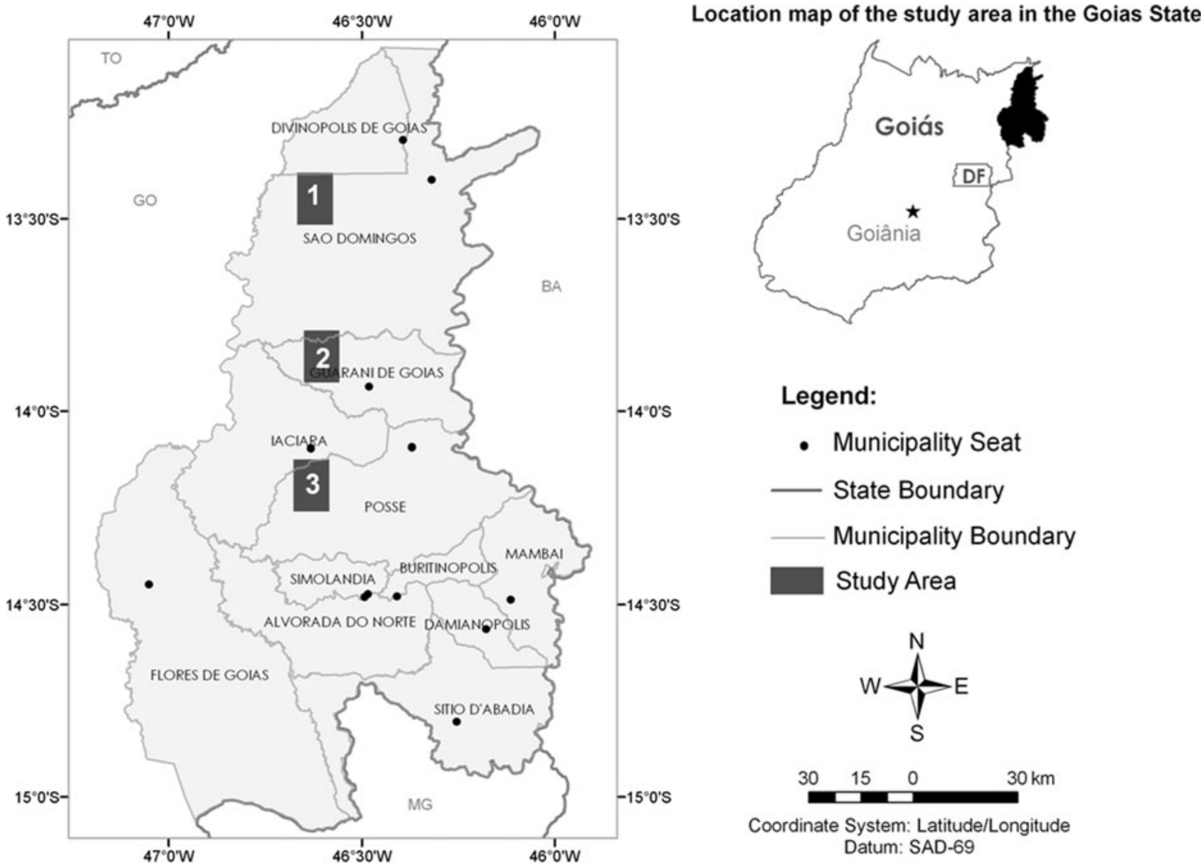

Fig. 1 Location map of the three study areas in the municipalities of São Domingos, Guarani de Goiás, and Posse selected for the simulation of the Paranã Valley landscape

respectively, and they were selected empirically after several tests with different combinations. The segments were classified using the ISOSEG unsupervised algorithm, converted into a raster format, and exported to the shapefile format. The segments were visually edited and reclassified on the computer screen with the support of the ArcGIS™ 9.3 geographic information system software package. Five land-use and land-cover classes were considered in this approach: pasture without weeds; pasture with weeds; undisturbed, natural vegetation; secondary forest; and others (agriculture, commercial reforestation, infrastructure). The goal of this step was to select pasture fields to be used in the proposed modeling.

Dynamics of pastures renovation

A set of 12 pasture fields with an average size of 57.5 ha, distributed in the three selected areas, was selected to evaluate the dynamics of pasture renovation in this region. In this case, a multitemporal series (1990–2009) of LANDSAT TM satellite images obtained from the homepage of the National Institute for Space Research was considered (Table 1). The images were georeferenced based on the orthorectified LANDSAT ETM + images (geocover) available at the homepage of the University of Maryland and projected onto a UTM projection system (zone, 23S; datum, WGS84; mean square error of georeferencing <0.5 pixels). The overpasses from May were prioritized because the vegetation was still mostly green (end of wet season) and the effects of cloud coverage in the LANDSAT images were not problematic (Sano et al. 2007). The criterion for selecting the site was the presence of bare soil in the 1990 overpass, the year of the first multitemporal series. By verifying bare soil in the pastures selected along the selected time period, it was possible to estimate the frequency of pasture renewal in the region of Paranã Valley. The presence of bare soils in the LANDSAT color composites was used as an indirect indication of pasture renewal.

Quantitative evaluation of life fences

The total length of the existing fences in the three selected areas was estimated by a visual analysis of the available images in the Google Earth™ program and by setting the scale on the computer screen to 1:15,000. The image analysis was then validated by a field campaign conducted in August and September 2010. A set of 30 image-based measurements was assessed in the field using a conventional 50-m measuring tape, and the average distance between stakes was measured using a measuring tape. The roads with fences on both sides were considered as having only one fence because of the difficulty in differentiating them in the satellite images considered in this study.

Table 1 Overpasses of the LANDSAT satellite images used in this study for the analysis of the average time of pasture renewal in the study area

Years	Path/row	
	220/69	220/70
1990	May 20	May 20
1991	May 23	May 23
1992	May 09	May 09
1993	May 12	May 12
1994	June 16	June 16
1995	Cloud	May 18
1996	June 21	June 21
1997	June 24	June 24
1998	June 11	June 11
1999	June 14	June 30
2000	May 31	May 31
2001	May 02	May 02
2002	Cloud	Cloud
2003	August 12	August 12
2004	Cloud	June 27
2005	June 14	May 13
2006	June 17	June 17
2007	May 19	May 03
2008	Cloud	July 08
2009	June 09	June 25

The scenes that presented cloud cover were not analyzed and are marked in the table by "cloud"

Estimating number of isolated trees

The average number of isolated trees present in the pasture fields in Paranã Valley was estimated based on the visual analysis of the SPOT images available in the Google Earth program. The estimation was conducted considering 30 pasture fields of ~1 km × 1 km in size distributed along the entire Paranã Valley in order to obtain good representation of the current scenery. The fields were divided into 100 subareas (i.e., 3,000 fields of 1 ha each), and the average and highest densities of the isolated trees were selected for further modeling.

Simulating live fence adoption and isolated trees increasing

The increase in crown coverage by replacing wooden fences for live fences was estimated considering a 4-m buffer zone. This zone is in agreement with the average crown diameter of the tree species used for live fences in Costa Rica and Nicaragua (Harvey et al. 2005). To simulate isolated trees increasing, we considered the highest density of isolated trees found in the 3,000 analyzed pastures. The estimation of the crown coverage of the isolated trees was performed considering 12 m^2 as the typical coverage of one tree.

The results obtained from the three validation sites were extrapolated for the entire region of Paranã Valley. In this case, we prepared a map of pastures using the LANDSAT TM images (path/rows: 220/69, 220/70 and 221/70) with overpasses from May 26 to June 20 in 2007. The scenes were georeferenced based on geocover images and, again, projected onto the UTM projection system (zone, 23S; datum, WGS84; mean square error of georeferencing, $<$0.5 pixels). The scenes were processed by image segmentation (growing region option; values of similarity and area set as 30), and the segments corresponding to cultivated pastures were visually selected on the computer screen.

Number of trees and hectares prevented from being logged for fence posts

To estimate the number of trees and hectares prevented from being logged for fence posts, the amount of posts produced per tree and the number of trees per hectare of the most common species used for wooden stakes were estimated, namely aroeira (*Myracrodruon* *urundeuva* Allemão), ipê (*Handroanthus impetiginosus*) (Mart. ex DC.), Mattos, and gonçalo-alves (*Astronium fraxinifolium* Schott) (Vieira and Scariot 2008). The average amount of wooden stakes (typically triangular with 15-cm equal side widths) produced per tree was estimated by interviewing two timbermen from São Domingos Municipality (Mr. Ronan and Mr. Domingos). The average amount of wooden stakes is tree diameter dependent. The minimum value of diameter at breast height (DBH) is ~30 cm, and trees with DBHs of 30–40, 40–50, 50–60, and 60–70 cm can produce 32, 36, 40, and 56 stakes, respectively.

The average number of trees per each DBH category was obtained by a field survey in three plots (total area: 4.8 ha) located in the municipality of São Domingos (reanalyzed from Vieira and Scariot 2008). The amount of stakes produced per hectare of forest was calculated by multiplying the number of stakes per tree by the number of trees per hectare and per DBH category (Eq. 1):

$$\text{Number of stakes/ha} = \sum (\text{number of stakes/tree/DBH category} \times \text{Number of trees/ha/DBH category}) \quad (1)$$

Results

Dynamics of regeneration of pastures

We found that the average time of pasture renewal is 8.1 ± 3.2 (SE) years (Fig. 2).

Quantitative evaluation of live fences and isolated trees

It was estimated 842 km of fences in the 450-km^2 studied plots (1.87 km/km^2); the usual distance between stakes is 5 m, that is 200 stakes/km or 374 stakes/km^2. The average number of isolated trees/ha was 3.9 ± 8.2 (SE), with a maximum number of 48 trees/ha.

Simulating live fence adoption and isolated trees increasing

If all of the wooden fences were replaced with live fences and considering a live fence as a continuous linear canopy 4 m wide, 842 km of fences would result in an additional 33.7 km^2 of vegetation coverage (7.48 % of the total area; Fig. 3).

If all pastures of Paranã Valley had 48 trees/ha with crown areas of 12 m^2, this would result in 25.9 km^2 of crown coverage in 450 km^2 of pastures in the Paranã Valley landscape (9.5 % of the total area of pasture or 14.3 % of additional crown coverage for the total crown cover).

The forest remnants of the region present an average of 22 trees of *H. impetiginosus*, three of *A. fraxinifolium*, and 14 of *M. urundeuva* per hectare, with DBH values > 30 cm; thus, the potential production is 1,472 stakes/ha (Table 2). Considering the typical distance between stakes (5 m) and an estimated 1.87 km of fence per km^2, this density would result in 200 stakes/km or 374 stakes/km^2. Considering the trees with DBH values > 30 cm, each hectare of native forest can produce stakes for 7.36 km of fence or 4.7 km^2 of terrain. According to the pasture map of 2007, there is approximately 1,086,200 hectares of pasture in the study area, indicating that approximately 2,311 ha of natural forest is exploited for each round of fence renewal (approximately 20 years according to local workers).

Discussion

The pasture renewal frequency in Paranã Valley is in the range of other regions of Brazil (Sparovek et al. 2007). However, the reasons vary: the major driving force causing the loss of pasture productivity, and consequently pasture renewal, in other regions of Central Brazil is mostly soil decline, which causes a reduction in productivity (e.g., Vera et al. 1998; Dias-Filho 2007). In Paranã Valley, the most important motivation for pasture renewal appears to be tree sprouting and weed infestation. The effective root and trunk sprouting of several tree species is a remarkable trait of deciduous forests (Vieira and Scariot 2006), and such a capacity can persist for 40 years even for pasture fields renewed several times during this time period (Vieira et al. 2006; Sampaio et al. 2007). A previous study showed that the average tree density sprouting from pasturelands of different ages is approximately 0.5 individuals/m^2. However, this number can vary significantly depending on the level of pasture management (Sampaio et al. 2007).

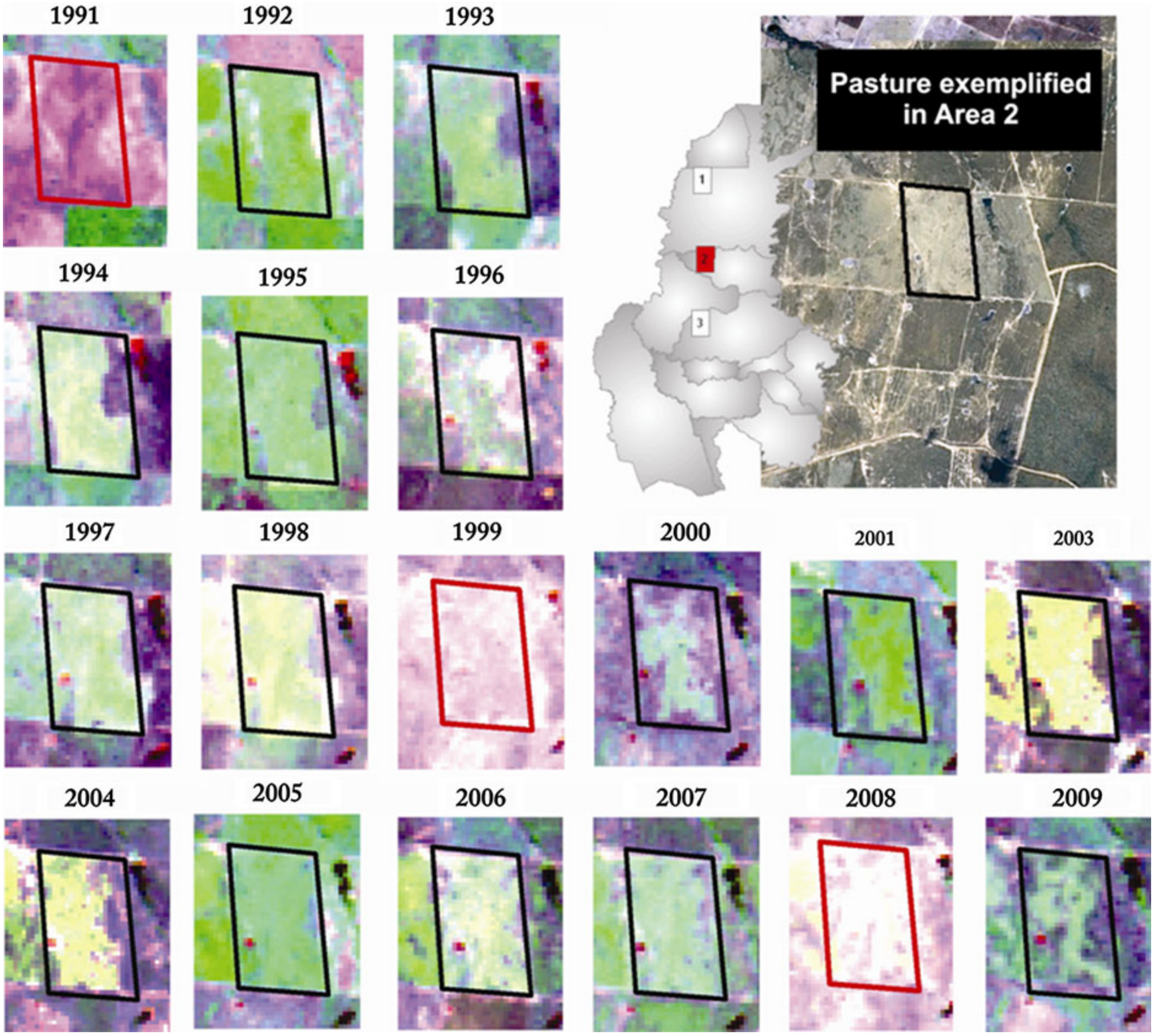

Fig. 2 Example of the dynamics of pasture renewal activity. The figure shows a sequence of LANDSAT color composites of bands 3, 4, and 5 obtained between the months of May and August over an area of cultivated pasture in the municipality of Guarani de Goiás. The bare soils (e.g., scene from 1991) are represented by *pink* or *light pink*, whereas the *green* pasture is shown by a *light green color* (e.g., scene from 2005). The gradations between *green* and *pink* indicate the presence of biomass that can be greener or drier, depending on the climatic seasonality specific to each year. Within this context, we can deduce that the pasture was removed for renewal in the years of 1991, 1999, and 2008, that is every 8 or 9 years. (Color figure online)

The high resilience of dry forests, promoted by a high resistance of the tree species to disturbance, suggests that managing the natural regeneration is an efficient strategy to enhance tree cover in pastures. The amount of isolated trees in pasture fields can be easily increased by maintaining the sprouting trees during the pasture renewal process. This strategy is more cost-effective than planting new and perhaps exotic tree seedlings because there are no costs related to nurse seedling production, planting, and protection from cattle. The management of pastures with a high density of regenerating trees can be performed using, for example, 2-m regeneration strips every 20–40 m. The high sapling (pole) density in these regeneration strips would prevent cattle browsing and trampling and be conducive to trees attaining a tall bole; once the

Fig. 3 Simulation of the substitution of wooden fences (*scenario 1*) with live fences (*scenario 2*) in the three study sites located in the municipalities of São Domingos, Guarani de Goiás, and Posse (sites 1, 2, and 3, respectively)

Table 2 Number of individual trees, number of stakes per individual, and number of stakes per hectare in the forests of the study area dominated by *M. urundeuva* (aroeira), *A. fraxinifolium* (gonçalo-alves), and *H. impetiginosus* (ipê)

Diameter (cm)	Number of individuals/ha	Number of stakes/individual	Number of stakes/ha
M. urundeuva			
30–40	8.8	32	280
40–50	7.5	40	300
50–60	3.1	48	150
60–70	2.5	56	140
A. fraxinifolium			
30–40	1.3	32	40
40–50	0.8	40	33
50–60	0.6	48	30
60–70	–	56	–
H. impetiginosus			
30–40	9.6	32	307
40–50	2.7	40	108
50–60	1.3	48	60
60–70	0.4	56	23
Total (number of stakes/ha)			1472

Source adapted from Vieira and Scariot (2008)

trees are tall, the strips would be thinned to promote the desired trees and permit grass colonization of the herbaceous strata.

Although the resprouting ability is strong in dry forests, the actual pasture renewal method does not permit the regeneration to advance, with only isolated trees remaining after deforestation. During the clear-cutting process for pasture planting, farmers first cut large trees selectively using chain saws and then remove the remaining vegetation often using chains tied to two bulldozers. The trunks and branches are often used for charcoal production. Farmers often leave several timber trees in the pastures for future harvesting; thus, isolated trees are continuously being removed by natural death or by harvesting for fence construction and other uses. As some pasturelands present a relatively high density of trees (up to 48 trees/ha), we can suggest that the farmers of Paranã Valley, to some extent, are unintentionally adopting silvopastoral systems, as already verified in other pasture-dominated regions of Central America and Mexico (Guevara et al. 2005; Sanfiorenzo-Barnhard et al. 2009). However, because the farmers continuously clear-cut the sproutings and do not replace the felled trees, there will soon be no trees remaining.

The average density of isolated trees found in the pasturelands of Paranã Valley (3.9 trees/ha) is in agreement with those found in tropical America, including those declared as silvopastoral systems in which farmers recognize several functions of trees (not only timber production) and manage their natural regeneration or even plant trees in pasture fields (1–7 trees/ha—Otero-Arnaiz et al. 1999, 41 trees/ha—Camargo et al. 2005, 8–33 trees/ha—Harvey et al. 2011). In addition to other environmental, ecological, and economic benefits, if every pasture field of Paranã Valley had a density of 48 trees/ha (pastures with the highest density found in the region), there would be a gain of 14.3 % of the total crown coverage in the region.

Because the region is dominated by pasture, the density of fences is high and is reflected in a large increase of crown coverage when the simulation involving the adoption of live fences is conducted. The landscape connectivity is also magnified, as shown in Fig. 3 and the data published by Harvey et al. (2005), León and Harvey (2006), and Pulido-Santacruz and Renjifo (2011). Additional studies are necessary to encourage the adoption of live fences by ranchers. In Brazil, studies involving recommendations for utilizing live fences have emphasized the use of exotic species (Matos et al. 2005), and studies on native species that would better fulfill ecological roles are limited. Carmo (2006) reported the use of castanheira-da-praia (*Bombacopsis glabra* (Pasq.) A. Rob.) in Santa Catarina State, and preliminary studies with red aroeira (*Schinus terebinthifolius* Raddi) were conducted by Cardoso et al. (2009). A study evaluated the potential of seven timber or fruit species that are commonly found in the dry forests of Paranã Valley. The species with some success were *Spondias mombin* L., *M. urundeuva*, and *A. fraxinifolium*, presenting 85, 23, and 23 %, respectively, of the root development by the end of rainy season (150 days) (Vieira et al. 2013). Independent of the stakes' success, live fences can also be established with seedlings or direct seeding; it is merely a matter of requiring more time for the fences to be established.

The dry forests of Paranã Valley have a high density of several large timber species. The 11,000 km^2 of pastures can be fenced with only 23 km^2 of forest.

Considering the current occurrence of dry forest in the region (1,900 km^2, Hermuche and Sano 2011), the maintenance of 23 km^2 of forest is significant. Moreover, the high density of woody species with a high economic value suggests another industry for the region: sustainable timer exploration, not from the almost-disappearing mature forest fragments, but from well-managed successional forests and silvopastoral systems. Indeed, logging to date is characterized by a low profitability and, in many cases, it is not authorized.

Conclusions

The dry forests of Paranã Valley have a high natural regeneration potential in pastures, which could be used for implementing silvopastoral systems. Our simulation involving the substitution of wooden fences with live fences and enhancing the density of isolated trees in the pasturelands showed that there would be a significant increase in tree coverage in this region. The timber tree availability in this ecosystem is very high, such that this region possesses the potential for implementing sustainable silvopastoral and forestry systems.

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