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Ecosystem services from converted land: the importance of tree cover in Amazonian pastures

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Abstract Deforestation is responsible for a substantial fraction of global carbon emissions and changes in surface energy budgets that affect climate. Deforestation losses include wildlife and human habitat, and myriad forest products on which rural and urban societies depend for food, fiber, fuel, fresh water, medicine, and recreation. Ecosystem services gained in the transition from forests to pasture and croplands, however, are often ignored in assessments of the impact of land cover change. The role of converted lands in tropical areas in terms of carbon uptake and storage is largely unknown. Pastures represent the fastest-growing form of converted land use in the tropics, even in some areas of rapid urban expansion. Tree biomass stored in these areas spans a broad range, depending on tree cover. Trees in pasture increase carbon storage, provide shade for cattle, and increase productivity of forage material. As a result, increasing fractional tree cover can provide benefits land managers as well as important ecosystem services such as reducing conversion pressure on forests adjacent to pastures. This study presents an estimation of fractional tree cover in pasture in a dynamic region on the verge of large-scale land use change. An appropriate sampling interval is established for similar studies, one that balances the need for independent samples of sufficient number to characterize a pasture in terms of fractional tree cover. This information represents a useful policy tool for government organizations and NGOs interested in encouraging ecosystem services on converted lands. Using high spatial resolution remotely sensed imagery, fractional tree cover in pasture is quantified for the municipality of

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Rio Branco, Brazil. A semivariogram and devolving spatial resolution are employed to determine the coarsest sampling interval that may be used, minimizing effects of spatial autocorrelation. The coarsest sampling interval that minimizes spatial dependence was about 22 m. The area-weighted fractional tree cover for the study area was 1.85 %, corrected for a slight bias associated with the coarser sampling resolution. The pastures sampled for fractional tree cover were divided between ‘high’ and ‘low’ tree cover, which may be the result of intentional incorporation of arboreal species in pasture. Further research involving those ranchers that have a higher fractional tree cover may indicate ways to promote the practice on a broader scale in the region.

Keywords Silvipastoral · Pasture · Amazon · Percent tree cover · Ecosystem services · Deforestation

Introduction

Large-scale conversion of forests to pasture is a primary means of transforming environmental productivity into high-yield economic systems worldwide. Loss of forest ecosystems results in a reduction or forfeiture of ecosystem services such as species habitat, conservation of soil and water resources, and carbon storage and sequestration (Brown and Lugo 1990; Costanza and Daily 1992; Daily 1997; Lubchenco 1998; Angelsen and Kaimowitz 1999; Hawken et al. 1999; Watson et al. 2001; Foley et al. 2007). The short-term economic benefits of this trade-off are self-evident in the large-scale conversion of forests everywhere. It is important to recognize, however, that these converted lands also provide ecosystem services and can be managed to maximize their environmental productivity (Björklund et al. 1999; Gren 2003; Tscharntke et al. 2005). While conservation and preservation efforts are necessary to ensure continued production of ecosystem services, the functions that converted land fulfill should be accounted for and encouraged. This study seeks to provide a methodology for assessing ecosystem services in a converted ecosystem and to account for current variations in land management practices that promote ecosystem services in deforested areas.

Throughout the tropical world, and especially in Amazonia, most deforestation results in the conversion of land cover to pasture for livestock production (Bushbacher 1986; Hecht 1993; Faminow 1998; Geist and Lambin 2002). This process has been challenged on various grounds, from its socioeconomic to environmental implications (Nepstad et al. 1999, 2001; Laurance et al. 2000; Cochrane 2001; Fearnside 2002; Laurance et al. 2002; Ferraz et al. 2003; Foley et al. 2007) with much attention given to the consequences for ecosystem services, particularly carbon storage and sequestration (Miles and Kapos 2008; Malhi et al. 2008; Nelson et al. 2009). Current trends in Amazonian pastures indicate that an integrated management system, incorporating forage species as well as trees, is nascent and likely to gain much ground in the coming decades (Foley et al. 2005; Naidoo et al. 2008; de Groot et al. 2010). The Brazilian Forest Code (Law 4771), established in 1965, currently mandates[1] that land managers in Brazil must leave Brazil nut trees standing, and maintain forested watersheds and a forested preserve on 80 % of the area of private land holdings (Vosti et al. 2003). While such measures may be imperfect in terms of enforcement and consequences for ecosystem functioning, there is recognition that converted land can provide substantial ecosystem services. These areas have begun to be regarded as ‘dual-use systems,’ (OECD

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[1] Brazil is presently in the process of reviewing its forest code with a strong contingent focused on reducing the amount of land that is required to be held in a forested reserve.

2005; Kim 2007) incorporating both economic and ecological productivity. Judging by the Brazilian and international attention paid to ecosystem services and the possibility for their remuneration, the concept of pastures as dual-use systems is likely to proliferate.

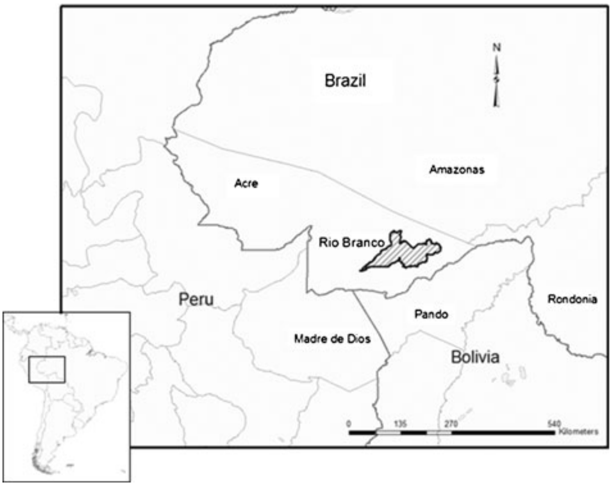
The purpose of this study is to account for the tree cover in pasture in the Southwest Brazilian Amazon, which provide valuable economic and ecosystem services (Pezo and Ibrahim 1998; Franke et al. 2001; Soares de Andrade et al. 2004; Barrett et al. 2009). We use a grid-intercept method with freely available remotely sensed imagery from satellite-based and airborne platforms to establish an appropriate sampling interval based on spatial autocorrelation. We then quantify fractional tree cover in pastures in the city of Rio Branco, Acre, Brazil. Finally, we discuss the significance of variations in fractional tree cover and the benefits of maintaining trees in a silvipastoral system.

Study area

The state of Acre, Brazil is located in the tri-national area of Peru, Bolivia, and Brazil (Fig. 1), and is at the Western terminus of the Arc of Deforestation that stretches across the southern Amazon. The capital city of Acre is Rio Branco, which has a concentrated urban area of 275,000 people and contains a substantial amount of pasture (Barrett et al. 2009). Undisturbed land cover in Rio Branco, Acre is mostly forest, a mixture of open and closed rain forests with and without bamboo (França 2002). About 13 % of the state of Acre has been deforested, and Rio Branco has experienced about 25 % deforestation, a moderate amount compared with other municipalities in the state (ZEE 2010, p 86). The pattern of deforestation follows the highways BR-317 to the west and BR-364 to the north. Historically, Acre has been isolated from markets located on the coast of Brazil. However, land-use change rates are expected to rise with the linking of the region to new markets precipitated by the paving of a major highway connecting the region to Peru and Bolivia (Brown et al. 2001; Brandon et al. 2005).

About 80 % of the deforested area in Acre is devoted to pasture, with very little cropland in the region (ZEE 2010, p. 84). The stocking density of cattle in Acre is about 1 head per hectare (ZEE 2000). This is twice the global average of 0.48 livestock units per ha, but the

Fig. 1 Study area: Rio Branco, Acre, Brazil



density is consistent with other areas of Latin America (FAO 2003). Some municipalities in Acre, including Rio Branco, have higher stocking densities (between two and three units per hectare), perhaps due to technological advances in pasture management or overly intensive land management practices (ZEE 2010, p. 155). The state government of Acre, a longtime stronghold of the socialist Worker's Party, has focused both on economic development of the region as well as environmental concerns such as stemming deforestation rates. Jorge Viana, the previous governor of Acre, dubbed his government the "Government of the Forest," reflecting broad support for ecological concerns in the region (Kainer et al. 2003).

The climate of Rio Branco in the state of Acre, Brazil is categorized as Af, according to the Köppen climate classification. The weather is characterized by heavy precipitation during the rainy season (roughly between October and May) contrasted with relatively low rainfall during the dry season, for an annual average of between 1,700 and 2,000 mm. Soils are primarily oxisols and ultisols, both of which store nutrients close to the surface and are prone to leaching.

Data

All image data used in the analysis were true-color composites with a spatial resolution of about 0.5 m. Fine-grain satellite imagery were used to evaluate the optimum sampling interval for studying fractional tree cover in pasture. Aerial photographs from a broad sampling area across the municipality (Fig. 2) were then used to quantify fractional pasture tree cover in Rio Branco. All georectification and orthorectification were performed prior to image access, and appeared satisfactory for areal analysis. It should be noted that absolute position was not necessary for this study, and small errors in position would not affect the analysis of fractional tree cover.

Fine grain satellite imagery were accessed using the Google Earth software, which displays fine-grain imagery from the Digital Globe sensors (QuickBird and WorldView-1). The imagery are from 2002 and 2004, resolution is variable, and appears to be comparable to

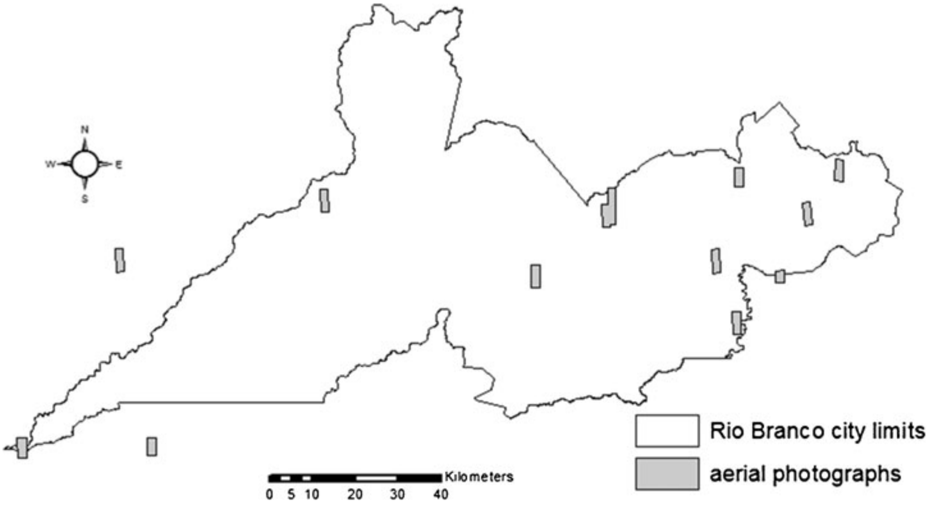


Fig. 2 Map of aerial photographs available for the region. The three westernmost images were not used in the analysis because they did not contain pasture land or were not located within city limits

that of the aerial photographs, about 0.5 m (in one pasture a group of cattle is distinguishable). All access and analysis of imagery using Google Earth was done in accordance with the end user license agreement.

The digital aerial photography of the municipality of Rio Branco was recorded in July of 2005 for the Mayor's office of Rio Branco, for use by ZEAS (Economic, Environmental, Social, and Cultural Zoning). ZEAS is a unique rural planning effort in the Amazon that involves the participation of various sectors including rural communities, academics, and local government and other public sector entities. The photographs were taken in 2005 in the rural portions of the state capital, Rio Branco and neighboring municipalities (Fig. 2). The photographs have three bands in the visible spectrum (blue, green, and red). The images cover 1.2 % of the total area of Rio Branco. The minimum resolvable unit of the imagery is 0.3 m.

Methods

Pastures in Google Earth images were overlaid with grids of progressively coarser resolution to determine the minimum sampling distance that would preserve accuracy in assessing fractional tree cover. The optimum sampling distance was also evaluated using a semivariogram approach. Pastures in the aerial photographs, which were more widely dispersed throughout the municipality, were then evaluated using the optimum grid cell size.

The grid intercept method was used in place of an automated approach such as image classification because (i) only three reflectance bands were available and notably lacking was near infra-red reflectance, which is generally most useful at discriminating between vegetation types, and (ii) most methods for deriving canopy cover from remotely sensed data are based on a "L-resolution" scene model (*sensu* Strahler et al. 1986), the spatial resolution is coarser than the objects of interest (i.e., several tree crowns per pixel), while in this case the imagery was "H-resolution" (i.e., several pixels per tree crown) and (iii) mapping entire tree crowns as polygons would be far more time consuming than evaluating individual points for tree presence/absence.

Sampling interval

In this analysis spatial autocorrelation was used to perform the analysis more efficiently by determining the optimum sampling interval. Studies frequently aim to minimize spatial autocorrelation to reduce redundancy of sample observations (e.g., Riitters et al. 1995; Brennan et al. 2002; Dormann et al. 2007; Andrew and Ustin 2009). Methods for assessing spatial autocorrelation can be found in Isaaks and Srivastva (1989), and Fischer and Getis (2010) provide a more applied analysis of the challenges of autocorrelation and its rectification in human environments and natural ecosystems. When the spatial autocorrelation of observations is high, the redundancy translates into hours of extra work for no tangible benefit. This time could have been better spent sampling more pastures at a coarser spatial resolution to give a broader estimate of tree cover in pasture.

To create the semivariogram, the lag or distance between samples at which the algorithm will evaluate variance is determined by the user. The number of lags to evaluate and/or the cutoff percentage of the image at which to end the evaluation is similarly user-specified. In this instance, the point data used to determine fractional tree cover were then used to create semivariograms to evaluate the spatial dependence in the data. The distance between adjacent samples was used as the minimum lag to be sure that each observation is included in the analysis, consistent with similar analyses (Coombes 1997). Because these were located on a regular grid it is easy to see the effect of distance on spatial variance (Fig. 3). Finally, the researcher must indicate the direction (range=0 to 360 degrees) to be evaluated. The algorithm will proceed in a given direction, recording variance at the lags specified by the user. A tolerance factor (e.g. plus or minus 20 degrees) may also be introduced in the specification of the direction, which is useful if observations are not located on a regular grid (Isaaks and Srivastva 1989).

Common features of semivariograms include the 'nugget,' or the immediate jump in variance seen close to the origin. The 'sill' is the position along the y axis at which variance levels off and spatial dependence has subsided. The sill was used in this analysis to determine the optimum sampling interval. The ideal sampling interval is a balance between having enough points to characterize a sample plot sufficiently, though not so many that observations fail to satisfy the independence criterion.

An additional method of testing for data redundancy is to sample using a progressively coarser sampling grid. If the sample results from a coarser spatial resolution do not differ sufficiently from those at a finer scale, there is no justification for the added effort involved in producing a more detailed sample. This assertion was used to design a second inquiry wherein the percentage of tree cover in pasture was observed first at 0.00005 degree grid cells, and then devolved to 0.0001, 0.005, 0.0005, 0.001 and finally 0.05 degree grid cells (corresponding to 5.5, 11, 22, 55, 110 and 220 m, respectively). These sampling intervals span a range of likely oversampling (i.e., some tree crowns covered multiple intersections) to undersampling (i.e., not enough points to characterize fractional tree cover).

Fractional tree cover

Pastures in the region of Rio Branco were identified by their characteristic mechanized appearance (large in size and nearly uniform in texture) and extent on the landscape. The area to be sampled was demarcated in the imagery by visual observation of a homogeneously managed contiguous area, characterized by a similar hue and texture, as well as features such as trodden paths and small reservoirs. This technique may not have included entire landholdings, as many ranchers often employ more than one management technique on the same property. Water bodies and their forested buffer zones were masked from the sampled area. Trodden paths, given their small area relative to the pasture, were not masked. Large dense clusters of trees of about 0.5 ha or more in pasture were also masked from the analysis, as isolated trees were of primary interest.

The selection of pastures for analysis was arbitrary and distributed as much as possible throughout the available imagery. Pastures were chosen by first framing an area at a coarse spatial resolution of high disturbance outside of urban areas, as these were primarily pastures. The pasture at the very center of the frame was chosen for analysis. It is unlikely that bias was introduced using this method, as pastures occupy almost all of the converted land outside of the urban center, and it was impossible to determine which pasture would be selected given the broad spatial extent covered by the frame used for pasture selection.

Once identified, the pastures were delineated to exclude riparian buffers and bodies of water. While buffer zones may in fact be grazed and are not generally fenced off from the pasture area, such buffers were excluded from this study because they are not part of the actively managed pasture system. The pastures thus demarcated were overlaid with a grid of cells measuring 0.0001 by 0.0001 decimal degrees (about 11 m squared) and each grid intersection represented a point that was sampled for tree presence or absence. The same sampling technique was performed again using grid cells measuring 0.00005 by 0.00005 decimal degrees (about 5.5 m squared), without referring to the data collected using a coarser sampling resolution. The purpose of this nested sampling design was to establish the optimal sampling interval for monitoring trees in pasture. The average area of pasture sampled was 89 ha (min=21, max=146).

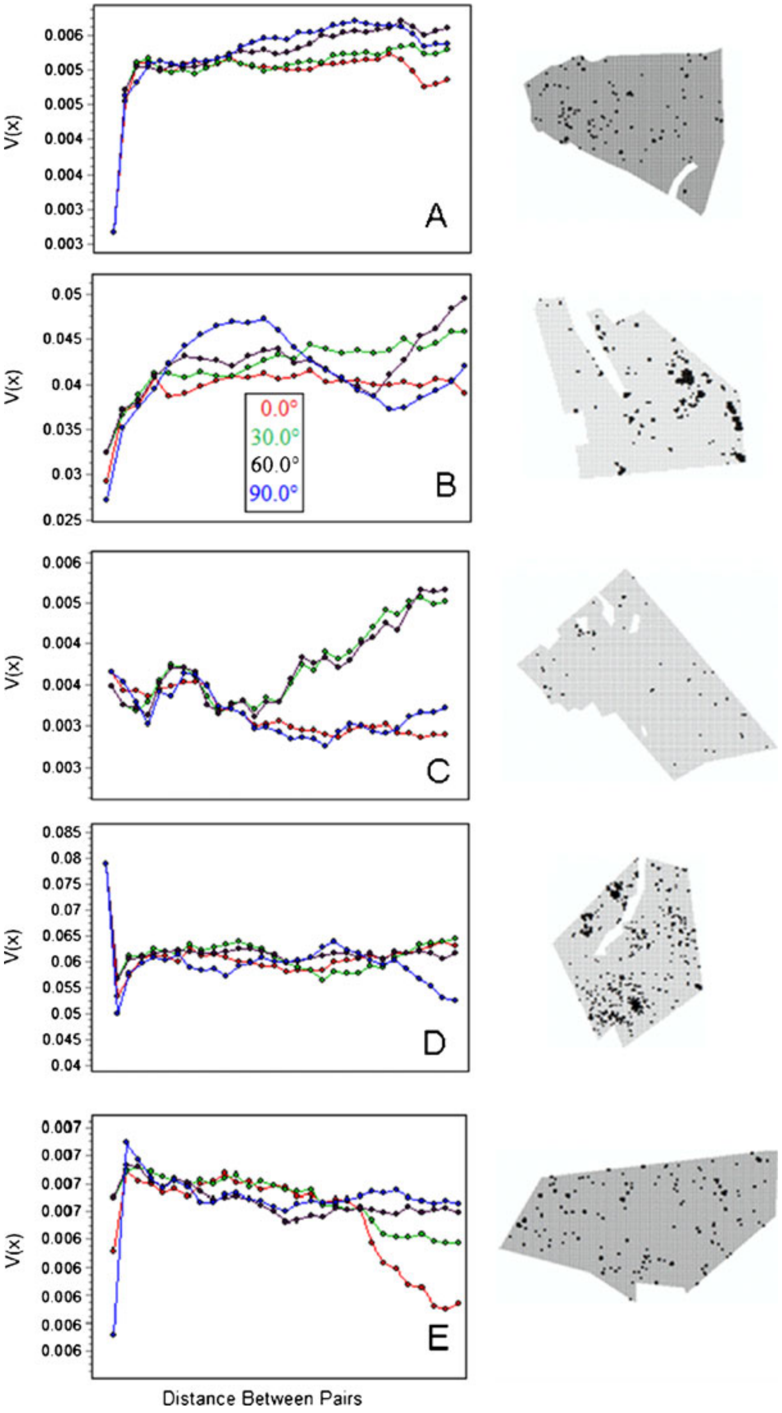


Fig. 3 Graphic representation of distribution of trees in each pasture (scale varies), and accompanying semivariogram showing the effect of distance on spatial dependence in **a**. Pasture 1 (**b**). Pasture 2 (**c**). Pasture 3 (**d**). Pasture 4 (**e**). Pasture 6 (**f**). Pasture 7 (**g**). Pasture 8 (**h**). Pasture 9a (**i**). Pasture 9b

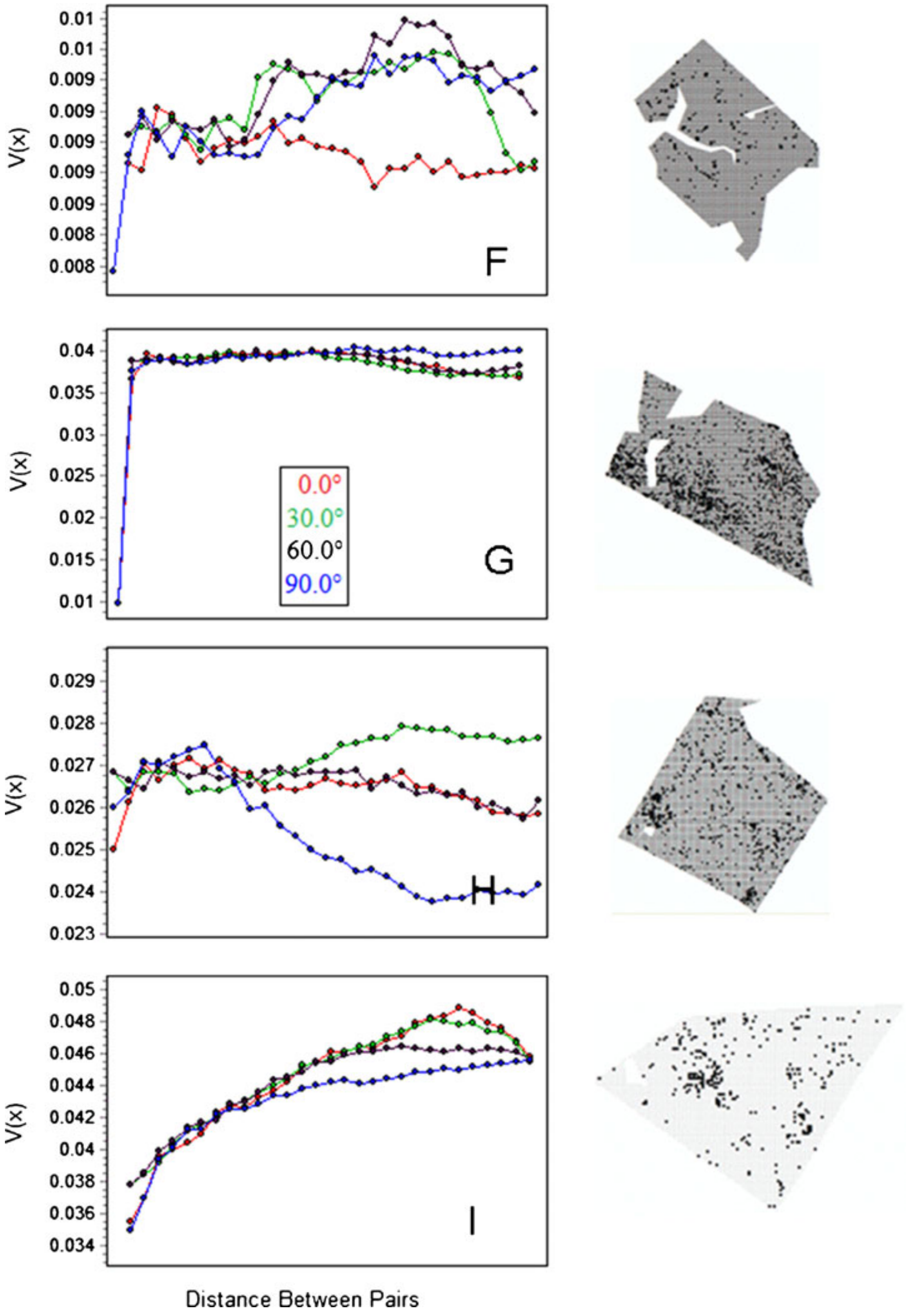


Fig. 3 (continued)

For both the 11 and 5 m grid cells, tree cover was noted as binary (1=present, 0=not present). The fractional tree cover was calculated as the number of sample points exhibiting tree presence divided by the total number of sample points per pasture and multiplied by 100 to obtain a percentage value.

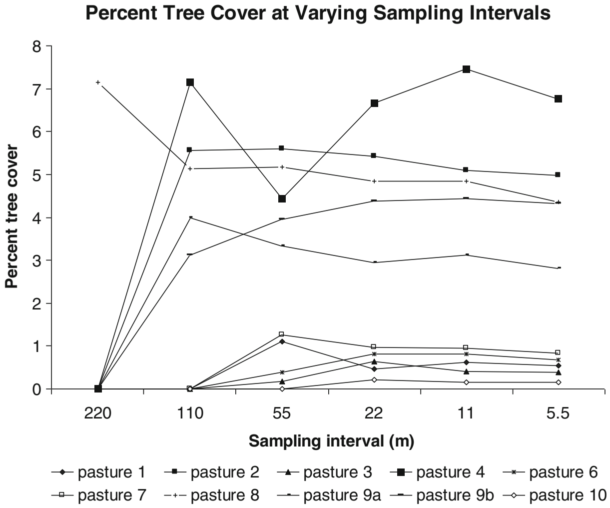
Results

Sampling interval

For most of the pastures evaluated, the sill was reached in five lags, or at a sampling interval of 55 m. This is the distance at which there is minimal or no spatial autocorrelation between samples. The semivariograms in Fig. 3 representing the spatial autocorrelation in tree cover data are not, however, uniform. The variation in these observations stems from a number of factors, including the prevalence of trees in pasture, their spatial distribution, and perhaps the shape of the sample plots as well. All of the semivariograms exhibit the same characteristic "jump" in variation from the origin to the beginning of the sill, although the length and height of this jump varies widely among the sample plots. Pasture 4 has an unusual drop in variance from 0.08 to 0.05 in the first lag, only to follow the expected pattern at greater lag distances. The cause of such an anomaly is not entirely clear, though it most likely an artifact of the data, perhaps due to the shape of the area sampled. Pasture 2, which also has an irregular shape (the result of masking out waterways from the analysis), has a similarly high variance of 0.06. The size of the area sampled should not influence the semivariogram, as the number of lags and lag distance is the same for each pasture, regardless of size.

Figure 4 demonstrates the effect of sampling pastures for tree presence/absence data at progressively coarser spatial resolution from 5.5 to 220 m cells. According to this method of determining the most efficient sampling interval, the proper spatial scale of observation of this phenomenon is no coarser than 22 m. At a finer spatial resolution, the fractional tree cover does not vary considerably; at a coarser resolution the estimates are not consistent with observations at a finer scale. The fractional tree cover estimated from 22 m grid cells is slightly higher than that of the finest scale employed, by an average of 1.47 percentage points. The sampling interval of 22 m was used in determining fractional tree cover in pastures because although spatial autocorrelation is still a factor at this interval, a coarser sampling grid does not perform as well in categorizing tree cover.

Fig. 4 Percent tree cover at progressively finer sampling intervals



Fractional tree cover

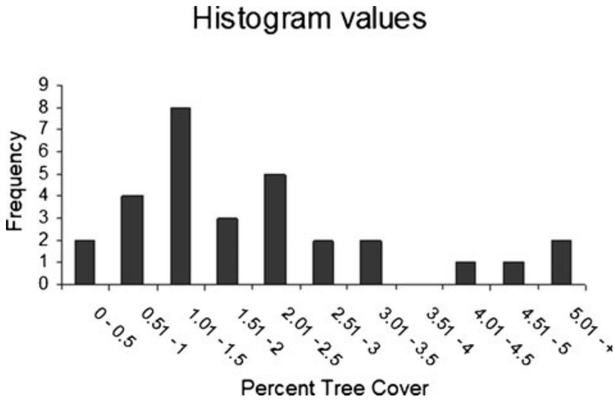
For those pastures with percent tree cover less than 2 %, the estimate at 22 m varies from that at 5.5 m by an average of +0.09. This number is used as a correction factor for the pastures with less than 3 % tree cover sampled using aerial photography (observed percent tree cover at 22 m * 0.91). In pastures with percent tree cover greater than 2 %, estimate of tree cover using a 22 m sampling interval leads to an estimate of percent tree cover different from that observed at 5.5 m by +0.20. Pastures observed using aerial photography with tree cover greater than 3 % are therefore corrected using this factor (observed tree cover at 22 m * 0.8).

The average tree cover in pastures observed from aerial photography was 2.05 %, or 1.78 (standard deviation=1.70 and 1.35, respectively) after adjusting for the use of a coarser spatial resolution (Table 1). The maximum tree cover observed was 8.37 % (6.70, adjusted) and the minimum was 0.08 (0.07, adjusted). The range of areal extent of pastures observed

Table 1 Pastures observed from aerial photography: area, percent tree cover observed at 22 m grid cell intersections, and tree cover adjusted for coarse sample interval

Pasture	Area (ha)	Percent tree cover (raw)	Percent tree cover (adjusted)
1	64	0.08	0.07
2	79	0.31	0.28
3	114	0.56	0.51
4	103	0.57	0.52
5	305	0.59	0.54
6	32	0.76	0.69
7	107	1.06	0.96
8	91	1.13	1.03
9	42	1.17	1.06
10	85	1.21	1.10
11	23	1.27	1.16
12	171	1.37	1.25
13	30	1.48	1.35
14	79	1.49	1.36
15	144	1.74	1.58
16	73	1.75	1.60
17	43	1.81	1.65
18	74	2.06	1.87
19	48	2.25	2.04
20	106	2.31	2.10
21	98	2.39	2.18
22	61	2.50	2.28
23	34	2.58	2.34
24	432	2.67	2.43
25	51	3.10	2.48
26	45	3.29	2.63
27	33	4.25	3.40
28	92	5.57	4.45
29	93	8.37	6.70

Fig. 5 Frequency (number of patures) with a range of percent tree cover, observed using a sampling interval of 22 m



(between 26 and 432 ha) warrants the use of an area-weighted mean and standard deviation to privilege estimates from larger areas. The area-weighted average of tree cover in pasture was 1.85 (standard deviation=1.62) employing the fraction adjusted for coarser sampling resolution.

Histograms of the fractional tree cover in pasture observed (Figs. 5, 6, and 7) show the differences between raw and adjusted estimates (frequency reported in number of pastures), as well as an area-weighted observation (frequency expressed in hectares). The raw estimate produces a histogram with a peak between 1.01 and 1.5 fractional cover, while the adjusted estimate exhibits a bi-modal histogram with peaks at 1.01–1.5 and 2.01–2.5 % cover. All three histograms show progressively fewer pastures or smaller areas with tree cover up to 0.05 or greater. The area-weighted histogram peaks at 2.01–2.5 with more dense tree cover having a smaller spatial extent.

One pasture that exhibited an extreme value (13.7 % tree cover) was excluded from the analysis. This pasture fragment was judged not to be representative because only small portion of the pasture area was visible from the aerial photograph, and the part which was evaluated was smaller than any other pasture or pasture fragment analyzed here (26 ha).

Discussion

The average tree cover in the study area is generally fairly low (1.85 %). This average figure, however, obscures the apparent grouping of pastures into two categories. There is one group of pastures with about one percent tree cover or less, and those with about 3 % tree cover or more. If we categorize the pastures based on this stratification, there is an average for pastures with "high" tree cover (mean=4.65, *n*=5) and another for those with "low" tree cover (mean=0.52, *n*=5).

The apparent grouping of pasture management into high and low fractional cover may be indicative that some land managers in the Rio Branco already intentionally incorporate trees in pasture management. The typical formation of pasture in the Amazon involves cutting down nearly all of the trees on a land parcel, perhaps selling the more lucrative species if there is a market for them, leaving the cut vegetation to dry, and burning the debris before seeding with forage species (Uhl et al. 1988; Skole et al. 1994; Walker et al. 2000). This system efficiently transfers many of the biomass nutrients to the soil for use in the new pastures, initially eliminates most insect pests, and can be practiced by large-scale and smallholder producers alike. The pastures with low tree cover are those which contain only

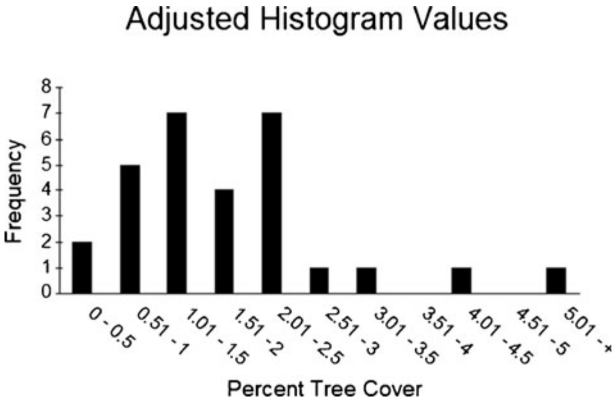


Fig. 6 Frequency (number of pastures) with a range of percent tree cover, adjusted for coarse sampling interval

the trees that are minimally necessary to provide shade to cattle and those protected by law. Pastures with higher fractional tree cover may occur for several reasons, including a higher proportion of protected trees, dual-management of pastures for additional products such as nuts, oils, or fruit. Higher fractional tree cover could result from trees left standing when the pasture was converted from forest, or trees that were planted after the land had been cleared. Further information is necessary to definitively explain why some pastures are characterized by higher tree cover, but the presence of such pastures is an encouraging sign that there is a plurality of land management options that includes denser tree cover in pasture.

Brazilian ranchers are federally mandated to leave Brazil nut trees standing when forest is cut for pasture (Glastra 1999), and according to the current Forest Code only 20 % of a landholding can be deforested (Vosti et al. 2003), and forested buffers are required along water bodies (Barrozo Simões et al. 2001). Of course, compliance with the Forest Code is not always enforced, and the survival of individual trees without the surrounding forest is dubious. There are, however, deforested areas that maintain economic and ecological productivity, and these areas have begun to be regarded as 'dual-use systems,' (OECD 2005; Kim 2007). The dual-usage of pastures for cattle production and ecosystem services is similar to the now-familiar idea of agroforestry systems, whereby crops are mixed and incorporated with tree species, and perhaps serve tertiary functions such as bee-keeping

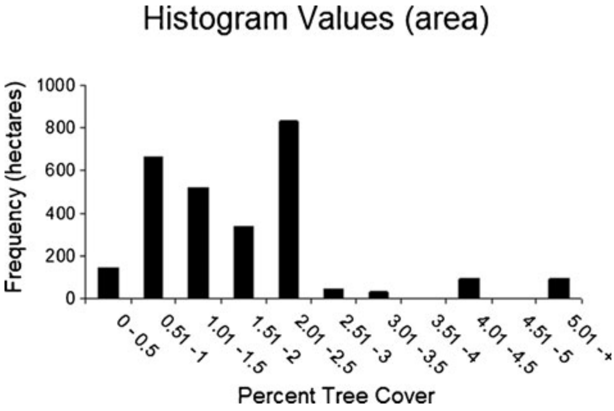


Fig. 7 Frequency (hectares) with a range of percent tree cover, observed using a grid of 22 m cells and adjusted for the coarse sampling interval

(refer to the journal Agroforestry Systems for more information). This diversification of production is more economically sound than depending on a single crop, maximizes biodiversity (Quental Rodrigues 2005), minimizes the threat of disease and pests common to monocultures, and protects soils from nutrient leaching, erosion, and over-drying (Sanchez 2004). Depending on tree density, the extension of a dual-use conceptualization of pastures can serve many of these same functions over a broader scale given the proportion of pastures to cropland in the Amazon.

Shade has been found to lead to an increase in the production of forage material in some pastures in the Amazon (Franke et al. 2001; Soares de Andrade et al. 2004). For the grasses most commonly found in the Southwest Brazilian Amazon, the effect of shade has been to reduce seasonality, or the differences in production of forage material in rainy and dry seasons (Franke et al. 2001; Carvalho et al. 2002; Mesquita Carvalho et al. 2002; Soares de Andrade et al. 2004). *Brachiaria brizantha* and *B. humidicola*, for example are able to adjust to a decreased influx of sunlight by devoting more primary production to leaf area than root matter (Dias-Filho 2000). While the overall biomass production may decrease as the result of reduced insolation, the actual forage material under such conditions increases (Dias-Filho 2000). The grass may be more vulnerable to drought and other stressors due to decreased root mass, however (Dias-Filho 2000). Trees also provide nutrients to the pasture in the form of leaf litter and debris (Franke et al. 2001). The roots of trees, being deeper than those of forage species, can tap into nutrients out of reach of grasses and herbaceous leguminous species (Franke et al. 2001), which may be particularly important where nutrient leaching has occurred. Trees in pasture provide a valuable ecosystem service by effectively re-introducing such nutrients to the pasture system.

A study of *Brachiaria brizantha* cv. Marandu, *Panicum maximum* cv. Massai, *Brachiaria humidicola* cv. Quicuio-da-amazonia, and *Paspalum notatum* cv. Pensacola, and other leguminous forage species found that the most common grasses used in the Southwest Brazilian Amazon are highly shade tolerant (Soares de Andrade et al. 2004). The authors used translucent tarps to block 30, 50 and 70 % of incident solar radiation in pastures in the region. The result of the experiment was that the difference in forage primary productivity between dry and rainy season was reduced for all species (Table 2). All species studied increased primary productivity during the dry season in shaded conditions, owing to the reduction of moisture loss to high rates of transpiration. *B. brizantha* massai and *P. maximum* marandu both increased productivity of biomass (dry weight) at 30 % shading in comparison with productivity in direct sunlight in both dry and rainy seasons.

Arboreous species in pasture produce the same effect of reducing solar radiation and subsequent stress on forage species. The ideal amount of shading for efficient pasture management is between 30 and 50 %, the interval at which biomass of some common forage species increases productivity (Soares de Andrade et al. 2004). This level of shading can be obtained by using species that have sparser canopies that allow some sunlight through to the forage species underneath. Other factors to be considered in incorporating arboreous species in pasture include additional ecosystem services such as production of renewable resources including fruits, oils, and in limited circumstances firewood or timber.

The incorporation of tree species in pasture is a management practice that benefits land managers directly, with positive ‘externalities’ or unintended benefits in the form of ecosystem services. Using the data on forage production of four forage species in shaded and unshaded conditions in Acre from Soares de Andrade and colleagues (2004), it is possible to approximate the cost of not promoting trees in pasture. The amount of pasture in Rio Branco is calculated to be about 130,000 ha, based on a supervised land-use classification (Barrett et al. 2009). The rainy season lasts about 3 months, the rest of the year is rainy according to

Table 2 (From Soares de Andrade et al. 2004) Rates of accumulation of dry matter ($kg^{-1} ha^{-1} d^{-1}$) of four forage grass species under four degrees of artificial shading and the two yearly seasons

Forage species	Rainy season	Dry season	Rate of accumulation (%)[a]
No shade			
Marandu	56.1	35.6	64
Massai	56.3	28.6	51
Quicuio-da-amazônia	54	12.4	23
Pensacola	11	6.6	60
30 % shade			
Marandu	62.8	51	81
Massai	57.2	40.1	70
Quicuio-da-amazônia	49.2	30.2	61
Pensacola	13	14.7	113
50 % shade			
Marandu	48.1	48.7	101
Massai	47	34.7	74
Quicuio-da-amazônia	45.8	24.3	53
Pensacola	22.9	21.7	95
70 % shade			
Marandu	22.6	31.3	138
Massai	28.1	32.8	117
Quicuio-da-amazônia	7	9.1	130
Pensacola	9.6	15	156

[a] Proportion of dry matter accumulation in the dry season to that of the wet season

meteorological data available from the Universidade Federal do Acre (A. Duarte, unpublished). If we assume the four forage species used in the analysis are in equal abundance in pastures in Rio Branco, the amount of forage material they would produce each year in unshaded pastures is 1.8 Mt. If all of the pastures in Rio Branco were shaded 30 %, the production increases to 2.0 Mt, a difference of 10 %. If all pastures in Rio Branco were seeded with *B. brizantha* cv. massai, *P. maximum* cv. marandu, the species that performed best under 30 % shaded conditions, this amount increases to 2.3 Mt, an increase of 23 % over the initial hypothetical conditions.

“Managed” versus “unmanaged” pasture

In the Amazon, as in much of the rest of the world, the majority of deforested area becomes agricultural land, such as pasture (Geist and Lambin 2001). Often studies of land-use change distinguish managed or productive pasture (i.e., little secondary growth, implies mechanization and/or regular burning) from unmanaged or unproductive pasture (i.e., herbaceous and/or shrubby secondary may coexist with forage species, reducing the capacity of the pasture to maintain cattle). This distinction, while useful for communicating basic differences in pasture-types leaves much to be desired in terms of understanding the ecological function of these rangelands. The revision of terms commonly used to describe a gradient of natural to converted ecosystems has been developed for forests (Buchwald 2002; FAO 2005), and a similar nomenclature could be developed for pastures. Ironically, economically “unproductive” pastures have a higher productivity of biomass or species habitat than “productive” ones (Brown and Lugo 1990; Daily et al. 2001; Palm et al. 2005). In reality there are a multitude of forms of pasture management, and more pertinent information on pastures could be gathered to assess their ability to provide ecosystem services. For example, the species that are permitted to proliferate in addition to forage species may serve some secondary function, and therefore should not axiomatically be characterized as "unmanaged" pasture. The nomenclature should be adjusted to allow for ranchers to intentionally manage not just the need of cattle for grasses, but also the needs of the soil (Evans 1992; Montagnini et al. 1995), other animals (Daily et al. 2001), water (Hamilton and King 1983; Lal 1998; Chang 2006), and the atmosphere (Brown and Lugo 1982; Detwiler and Hall 1988; Houghton et al. 2000; Watson et al. 2001).

Unfortunately, many of the ways in which pastures could be more environmentally productive in terms of carbon sequestration are not implemented on such a scale that a distinction is yet necessary. Trends in Amazonian rangelands, however, indicate that an integrated management system is nascent and likely to gain much ground in the coming decades (Nepstad et al. 2002). While such measures may be imperfect in terms of enforcement and consequences for ecosystem functioning, there is recognition that converted land provides significant ecosystem services. Judging by the Brazilian and international attention paid to ecosystem services and the possibility for their remuneration, the concept of pastures as dual-use systems is likely to proliferate.

Conclusions

This study concludes that the optimum spatial resolution for sampling trees in large scale pasture in the study area is 22 m. A sampling grid based on geographic conditions resolves the problem of grid placement and facilitates integration of laboratory and field research. Using a sampling interval of 22 m, the mean percent tree cover in pastures in Rio Branco is 1.85 (standard deviation=1.62), according to area-weighted measurements. This value is meaningful in terms of large (>30 ha) pastures. The evaluation of large pastures in this analysis reflects their extent on the landscape, comprising roughly 80 % of the pastureland in Acre (ZEE 2000). Smaller holdings are increasing in their contribution to converted area, although this trend may reverse when the region is connected via the new highway to new economic markets which place a greater demand on large scale production (Brown et al. 2001; Naughton-Treves 2003).

The study of fractional tree cover in pasture indicates a separation of pastures with high (>3 %) and low (<1 %) tree cover, which may be due to intentional practices on the part of land managers. One feature often observed in the course of analysis was a smaller area (~20 ha), located in the corner of a pasture, which had a considerably higher density of trees. These areas may have been fallow or secondary areas, or dedicated silvipastoral systems. Identifying ranchers that have a higher fractional tree cover may indicate ways to promote the practice on a broader scale in the region, and could indicate additional benefits to those identified in the literature such as improved soil stabilization and fertility.

The benefits of higher fractional tree cover for land managers are increased forage productivity and more stable weight of livestock. Increased productivity has benefits both for the land manager who can stock animals at a greater density, as well as external benefits in the form of ecosystem services provided by forested areas that are less vulnerable to conversion. Pressure to convert surrounding forest to pasture decreases when the land needed to support a constant amount of livestock is reduced. Economically, the inclusion of trees may provide a secondary source of income. Trees in pasture also provide the ecosystem services of air and water filtration and soil protection.

The trees that are in the pasture maintain carbon in the form of biomass. If the trees are left standing during the conversion from forest, the biomass represents carbon that was not lost to the atmosphere during combustion or decomposition. If trees are planted after the pasture has been converted, the trees represent carbon that has been removed from the atmosphere. It is easier to incorporate arboreous species in pasture by leaving many trees standing in the process of converting forests. Forest trees have a proven resistance to fires that are used to clear and maintain pastures, and the planting of trees after pasture formation necessitates the erection of fences to ward off foraging cattle. The forest trees allowed to grow in pasture are immediately available to provide ecosystem services, as opposed to new trees which must become mature to have environmental benefits aside from carbon sequestration. The desirability of retaining forest trees in pasture should not undermine the efforts to plant new trees, however. In the long-term it may also be necessary to replace forest species with new trees, as these may not be able to reproduce in pastures.

The study of trees in pasture in the Southwest Brazilian Amazon obviates the necessity of an integrated production, or silvipastoral system. The findings of this study suggest that the discussion of dual-use production is both timely and necessary, as economic and ecological conditions can both be improved by such a synthesis.

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