DEGRADED PASTURE DISTRIBUTION AND WOODY ENRICHMENT STRATEGIES FOR PASTURE FERTILITY PRESERVATION IN THE BRAGANTINA REGION, NORTH-EASTERN AMAZON

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With 2 figures, 5 tables and 2 photos

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Summary: In the densely settled Bragantina region, northern Brazil, smallholder cattle pastures start into compulsory degradation processes indicated, among other factors by the woody encroachment of the resprouting secondary vegetation, nationally called "capoeira". By means of Landsat and QuickBird satellite imagery techniques different stages of tree-dominated pastures were identified and the distribution of degraded pastures quantified. This was tested in a supervised Landsat classification from 2006 and 2007, taking QuickBird imageries from 2004 and 2005 as additional ground checks. We found that 42% of the rural Bragantinian landscape has already converted into pastures, 28% in advanced stages of above ground pasture degradation. Our reclassification means that the region is still confronted with a serious ecological pasture problem and that conventional land use classifications, climatological models and carbon calculations, based on Landsat imageries only, underestimate pasture distribution and thus lead to inaccurate extrapolations. As the resprouting shrubs of the capoeira are a permanent problem on tropical lowland pastures but, on the other hand, are also the ecological basis of the sustainable slash-and-burn systems of smallholders, we tested some innovative strategies to tolerate various useful woody components of the capoeira on pastures to stabilise them ecologically: first, a buffet trial shows that the ten tested capoeira and some other common domesticated tree species obtain a comparable palatability as well-known woody forage legumes. Thus, *Cecropia palmata* and *Tithonia diversifolia*, among others, were as palatable for cattle as the well-known multi-purpose legume *Cratylia argentea*. As a consequence, these freely accessible tree species should not be slashed but fostered on pastures, like supplementary forage plants. Secondly, it is demonstrated that the multi-purpose forage legumes *C. argentea* and *Flemingia macrophylla* perform better under smallholder management than under large scaled farming or even intense management due to the associated prolonged restoration times. In sum, we could demonstrate that woody components (capoeira and/or woody legumes) are more appropriate for the humid tropics than pure grass-monocultures. Based on these experiences, we modified the model of a grass-capoeira-legume pasture, incorporating pastures just as an interim stage of the slash-and-burn system. Forage production could be enhanced in that system by selective slashing of the capoeira (palatable species are tolerated) and by incorporating woody forage legumes. As this biome is known to restore its ecosystem fertility rather in its above-ground biomass than in its poor soils, woody components on pastures are recommended for ecologically sustainable production systems. Furthermore, they might be requisite to mitigate the proclaimed climatic change in the Amazon.

Zusammenfassung: Auf neu angelegten Kleinbauernweiden im dicht besiedelten Bragantinagebiet im Norden Brasiliens setzen nach nur wenigen Jahren Degradationsprozesse ein, welche sich unter anderem durch das oberirdische Verbuschen der Weiden durch die schnell wieder austreibende Sekundärvegetation (Capoeira) äußern. Mithilfe von Landsat und QuickBird-Satellitenaufnahmen ist es möglich verschiedene Stadien von verbuschenden Weiden zu identifizieren und ihre Verbreitung darzustellen. Dies wurde mit einer überwachten Landsat-Klassifizierung der Jahre 2006 und 2007 überprüft. QuickBird-Szenen aus den Jahren 2004 und 2005 wurden zusätzlich zur Erstellung von Trainingsgebieten hinzugezogen. Unsere Ergebnisse zeigen, dass bereits 42% des rural geprägten Bragantinagebietes in Weiden umgewandelt worden sind, von denen sich insgesamt 28% in einem Zustand fortgeschrittener Verbuschung befinden. Unsere Reklassifizierung zeigt, dass es im Bragantinagebiet weiterhin ein gravierendes agrarökologisches Weideproblem gibt und dass Landnutzungsklassifizierungen, Klimamodelle und Kohlenstoffbilanzierungen, welche nur auf Landsat basieren, die Verbreitung von Weiden unterschätzen und zu ungenauen Hochrechnungen führen. Da die austreibenden Gehölze der Capoeira auf tropischen Flachlandweiden ein permanentes Problem sind, sie auf der anderen Seite aber auch die ökologische Grundlage für einen nachhaltigen Brandrodungswechselfeldbau bei Kleinbauern ist, werden innovative Ansätze getestet, gezielt ausgesuchte Gehölze auf den Weiden zu tolerieren und somit Rinderweiden ökologisch zu stabilisieren: So wird erstens in einem Büfett-Beweidungsversuch gezeigt, dass die zehn getesteten Capoeira- und andere lokal verfügbare Nutzbaumarten vergleichbare Schmackhaftigkeitswerte bei Rindern aufweisen, wie renommierte Futterleguminosen. Beispielsweise besitzen *Cecropia palmata* und *Tithonia diversifolia* die gleiche hohe Schmackhaftigkeit wie die multi-funktionale Futterleguminose *Cratylia argentea*. Diese für den Kleinbauern kostenfreien Gehölze sollten also auf den Weiden nicht abgeschlagen, sondern können

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als Ergänzungsfutter auf Weiden toleriert werden. In einem zweiten Versuch wird gezeigt, dass sich die multifunktionalen Gehölzleguminosen *C. argentea* und *Flemingia macrophylla* unter dynamischen und flexiblen Kleinbauernmanagement sogar besser entwickeln als unter extensiven Großgrundbesitzer-Weidemanagement oder Intensivkultur, da sie bei der ersteren über längere Regenerationsphasen verfügen. Die Ergebnisse zeigen, dass Holzkomponenten (Capoeira und/oder Gehölz-Leguminosen) auf Weiden in den humiden Tropen ökologisch angemessener sind als reine Grasmonokulturen. Darauf basierend wird das Modell einer Gras-Capoeira-Leguminosen-Weide verbessert, welches Weiden nur als temporäres Zwischenstadium im Brandrodungswechselfeldbau versteht, bei dem aber durch selektives Abschlagen (schmackhafte Arten werden toleriert) und angebaute Gehölz-Futterleguminosen die Futterproduktion gesteigert werden kann. Da die Fruchtbarkeit feuchttropischer Ökosysteme in der oberirdischen Biomasse und weniger in den Böden gespeichert wird, sind Gehölzanreicherungen auf Weiden für ökologisch nachhaltige Produktionssysteme also empfehlenswert. Außerdem spielen Aufforstungen auf Weiden und silvo-pastorile Systeme eine wichtige Rolle bei der Mitigation der prognostizierten Auswir kungen des Klimawandels in Amazonien.

Keywords: Pasture degradation, weed encroachment, remote sensing, Brazil, Quickbird, Landsat, cafeteria trial, capoeira, tree dominated pastures, pasture management, agro-silvo-pastoral system, pasture sustainability

1 Introduction

1.1 Amazonian deforestation for unsustainable cattle pastures

Cattle pastures are still a major concern in the rainforest discussion and remain a political issue debated internationally as they are known to be one of the leading implementations after deforestation in the Amazon (e.g. Buschbacher 1986; Downing et al. 1992; Fearnside 1993; Faminow 1998; Walker et al. 2000; Lal et al. 2000; Soares Filho et al. 2006). Transforming a biodiverse tropical forest into a grass-monoculture signifies a radical ecological change and leads to severe consequences in respect of ecosystem fertility, soil and water resources, biodiversity, along with meso- and microclimate (e.g. Uhl et al. 1988; Uhl and Kauffman 1990; Serrão and Toledo 1992; Lanfer 2003). However, even in anciently settled regions, grass-monocultures are criticised as inadequate for the humid tropics, as they produce a relatively low economic return and are ecologically unsustainable (Fearnside 1993; Mattos and Uhl 1994; Serrão and Nepstad 1996). Usually, pastures degrade within only 7-10 years after planting and are often simply abandoned for unproductiveness (Faminow 1998; Dias-Filho 2007). The main technological reasons of pasture degradation are said to be insufficient pasture establishment, neglected management, lack of investments, technology, and know-how (P and N fertilizer, legumes). The main ecological consequences are chemical and physical soil depletion (Serrão et al. 1979; Buschbacher et al. 1988) as well as bush encroachment (Photo 1). Insect pests and increasingly prolonged dry seasons accelerate the degradation processes by diminishing the forage grasses (Serrão and Nepstad 1996; Dias-Filho 2007). This particularly applies to smallholdings (<100 ha) lacking the technological and financial resources compared to large-scale farm enterprises (Portuguese: fazendas). Thus, from a stringent scientific point of view, cattle production in the Amazon cannot be recommended and other land use systems are economically and ecologically more adequate (Siegmund-Schulze 2002).

On the other hand, there are 13.2 million ha of pastures and 31 million cattle in North Brazil, 12.8 million of which are present in Pará State (IBGE 2008), surpassing the herd size of Germany (BMELF 2008). Therefore, it is not quite likely that cattle involvement will be detained in the following decades, as the ranching tradition is deeply rooted in the Latin American culture. For instance, Brazil is said to be one of the few nations where poor people, with a monthly income below 80 US$, can afford the regular consumption of beef (Teixeira Neto and Costa 2006). Consequently, besides the efforts to slow down further rainforest deforestation for cattle ranching, there should be, at the same time, incentives to improve animal production systems on already deforested lands (Serrão and Nepstad 1996). This would mean an intensification process in rural landscapes, currently slowly taking place in the first densely settled regions like the Bragantina region in the north-eastern Amazon.

Slash-and-burn systems have been carried out for the last one hundred years in the Bragantina region without the feared dramatic soil fertility decline. However, there are still doubts about their sustainability, even more as fallow periods are con-

Photo 1: Slightly degraded pasture (*Brachiaria brizantha*) on a large-scaled farm with single regrowing capoeira species.In the background some palatable *Attalea maripa* palms for cattle can be seen which are traditionally tolerated as shadow trees on pastures in the Bragantina region. Photo: Hohnwald, 01.10.2008, at Igarapé-Açu (47°33'05.03" W/ 1°09'38.61" S).

stantly shortened (Denich 1989; Baar 1997; Sommer 2000; Denich and Kanashiro 1998). Tree species within the fallow, unable to endure frequent slash-and-burning, vanished and those capable of surviving mechanical damages became dominant so that a robust and dense secondary vegetation was formed called "capoeira" in Brazil (Baar 1997; Photo 2). The capoeira consists of young trees, shrubs, woody and herbaceous lianas, grasses and other herbs, the woody components mainly regenerating from subterranean rootstocks, epicormic buds of stumps or from horizontal tap-roots (Clausing 1994; Denich et al. 2004). Its agricultural benefit is due to its high above-ground biomass accumulation providing a soil fertility peak in soils when slashed and burned for a subsequent cropping phase (Denich 1989). In all, more than 800 different plant species were identified within the Bragantinian capoeira (Baar 1997; Baar et al. 2004), the most important ones for ecosystem fertility *sensu* (Denich 1989) are listed in table 1.

Since the 1980s, cattle husbandry became so popular among smallholdings that scientists spoke of the "pecuarização" (= implementation of cattle) of the Bragantina region (Serrão and Nepstad 1996). Like other permanent and semi-permanent cash crops, pastures were usually taken out of the fallow-based system, which has to be seen critically in the case of smallholders, as the sustainability of the production system depends on the capoeira fallow. Today, animal production systems are quite heterogeneous in the region (IBGE 2008): Fazendas employ sophisticated technologies like artificial insemination and embryo transfer, even from São Paulo, to implement large-scale high-input-high-output beef production systems for international exportation. In contrast, smallholders mainly remain crop farmers (Billot 1995) and make use of animals rather as complementary assets or a flexible financial instrument, e.g. like a bank account (Siegmund-Schulze et al. 2007). For instance, smallholders just buy cattle for the financial return from crops and sell it again for the next crop investments, sometimes as early as half a year later (Siegmund-Schulze 2002). As pasture management is disregarded in such cases, forage grasses are hardly tended and systems become highly dynamic and flexible leading to accelerated pasture degradation (Dias Filho 2007).

Traditionally, pastures are considered as degraded from the animal production point of view in case capoeira recuperation surpassed 50–70% of the pastures' soil cover (Dias-Filho 2007), reflecting an animal capacity of less than 0.5 livestock unit per ha (Photo 2). It is estimated that 30 million ha (=50%) of cultivated pastures have reached that stage of degradation in the Brazilian Amazon (Serrão and Nepstad 1996; Faminow 1998). By now, however, no accurate data have been published. Therefore, the first objective is the classification and quantification of the above-ground pasture degradation stages. The study tries to provide answers on the urgent questions of how many pastures are really degraded and of how grave the problem of above-ground pasture degradation is in the Bragantina region.

Photo 2: Advanced degraded pasture (*Brachiaria humidicola*) with one-year-old capoeira on a smallholding. Photo: Hohnwald 26.08.2008, at Santa Isabel do Pará (48°08'26.49" W/ 1°16'57.53" S).

1.2 From grass-monocultures to agro-silvo-pastoral systems

Pasture cleaning from woody weeds remains a Sisyphean task in the phytodiverse humid tropics, both on fazendas and smallholdings, since capoeira species tend to continuously re-sprout and invade pastures (Uhl et al. 1988). As the natural reaction

Table 1: Scientific name and (sub)family of the most important woody capoeira species (I) *sensu* Denich (1989), the most frequent capoeira species (F) *sensu* Baar (1997), frequent capoeira species on pastures (W), palatable capoeira species (P) *sensu* Hohnwald (2002).

Species name	Family	I	F	W	P
Vismia guianensis (Aubl.) Pers.	Clusiaceae	X	X	X	
Myrciaria floribunda (H. West ex Willd.) O. Berg	Myrtaceae	X	X		
Myrcia deflexa (Poir.) DC.	Myrtaceae	X	X		
Myrcia bracteata (Rich.) DC.	Myrtaceae	X	X		
Banara guianensis Aubl.	Connaraceae	X	X		X
Lacistema pubescens Mart.	Lacistemataceae	X	X	X	
Rollinia exsucca (DC. ex Dunal) A. DC.	Annonaceae	X	X		
Rourea ligulata Baker	Connaraceae	X	X		
Myrcia cuprea (O. Berg) Kiaersk.	Myrtaceae	X	X		
Abarema jupunba (Willd.) Britton & Killip	Mimosoideae	X	X		X
Inga edulis var. *parviflora* Benth.	Mimosoideae	X	X		X
Memora flavida (DC.) Bureau a. K. Schum.	Bignoniaceae	X	X		
Bernardinia fluminensis (Gardner) Planch.	Connaraceae	X			
Senna chrysocarpa (Desv.) H.S. Irwin a. Barneby	Caesalpinioideae	X			
Davilla kunthii A. St.-Hil.	Dilleniaceae	X			
Phenakospermum guyannense (Rich.) Endl.	Strelitziaceae	X			X
Memora allamandiflora Bureau ex K. Schum.	Bignoniaceae	X			
Machaerium quinata (Aubl.) Sandwith	Papilionoideae	X			
Terminalia amazonia (J.F. Gmel.) Exell	Combretaceae	X			
Doliocarpus brevipedicellatus Garcke	Dilleniaceae	X			
Davilla rugosa Poir.	Dilleniaceae		X		
Casearia grandiflora Cambess.	Flacourtiaceae		X		
Annona montana Macfad.	Annonaceae		X		
Serjania paucidentata DC.	Sapindaceae		X		
Neea oppositifolia Ruiz a. Pav.	Nyctaginaceae		X		X
Myrcia sylvatica (G. Mey.) DC.	Myrtaceae		X	X	
Myrciaria tenella (DC.) O. Berg	Myrtaceae			X	
Borreria verticillata (L.) G. Mey.	Rubiaceae			X	X
Stachytarpheta cayennensis (Rich.) Vahl	Verbenaceae			X	
Rolandra argentea Rottb.	Asteraceae			X	X
Borreria latifolia (Aubl.) K. Schum.	Rubiaceae			X	

in the humid tropics on grass-monocultures always will be a strong forest succession, the use of the biomass instead of permanently trying to eliminate it with pesticides or slashing would be preferable - even more as the capoeira is known as the major nutrient source of low-input agricultural smallholder systems (Denich 1989). From a tropical ecologist's point of view tropical production systems need to be adapted and imitate the natural vegetation, the evergreen tropical rainforest in the Bragantina region (Ewel 1986; Loker 1994; Ewel 1999). However, humid tropical low-land forests hold their fertility in its above ground woody biomass by far, quickly getting lost when destructed (Vareschi 1980; Reichholf 1990; Weischet and Caviedes 1993; Odum and Barrett 2005). Poor tropical soils, in contrast to natural grasslands, e.g. in steppes, cannot store fertility in the soils to the same extent as they have a considerable lower cation exchange capacity. In order to preserve ecosystem fertility in the humid topics, the tree component on pastures has to be extended more extensively than in other biomes of the world. Contradictorily, for a productive animal production system, abundant forage grass biomass must be produced to aliment cattle. As a consequence, pastoral systems must be developed where the woody and the forage grass biomass are jointly maximised, equivalent to the idea of silvo-pastoral systems (Young 1989; Nair 1998; Veiga et al. 2000).

One promising agro-silvo-pastoral system approach proposed not to eradicate the resprouting secondary vegetation on pastures yet to tolerate it for nutrient accumulation (Loker 1994). This model attempted to integrate cattle into the slash-and-burn system of smallholders for a few years and the avoidance of area degradation after pasture use. While premeditated pasture degradation (= agricultural degradation *sensu* Dias-Filho 2007) by the re-sprouting capoeira is tolerated, biologically area degradation is prevented by the resprouting and nutrient enriching capoeira. Testing this model in a preceding study in the Bragantina region showed that even under the relatively high stocking rate of 1.5 animal units (= 450 kg)/ha/year, the floristic composition of the capoeira fallow was not significantly altered but maintained its full restoration potential. The animal effect defined there as trampling and browsing damages was negligible for capoeira maintenance (Hohnwald et al. 2006). The idea of a grass-capoeira pasture also appeared to fit better into the dynamic and flexible smallholder system as the farmer can always stop animal production whenever he chooses, by allowing the capoeira to grow (Hohnwald 2002). However, the major drawback of the system was that animal weight gains of a grass-capoeira pasture remained far behind a conventional pasture. This was due to the indirect fostering of unpalatable capoeira plants resprouting unharmed while the otherwise competitive forage grasses were intensively set back by animal grazing. Sustainable forage grass production could therefore be maintained for approximately one year only. Thus, the second objective of this paper is improving the pasture phase of this model and increasing forage biomass particularly for the second grazing year.

2 Materials and methods

2.1 Study region

The Bragantina micro-region of northern Brazil is a unique case of an intensively used rural region within the Amazon (Egler 1961) as it possessed an extraordinary dense rural population of 38.9 inhabitants/ km² in 1996 (IBGE 2008; MMA 2006). Traditionally, it is defined as the upstate of the metropolis Belém and stretches eastward to Bragança, as well as from the northern Atlantic coast to the river Guamá in the south (Fig. 1). However, according to Brazilian administrative subdivisions, Castanhal and Salgado (at the coast) are extra micro-regions, so that in a strict sense the “microrregião Bragantina” belongs to the “mesorregião do Nordeste Paraense” starting east of Castanhal (IBGE 2008).

The climate of the Bragantina region belongs to the warm humid tropical lowlands with median annual temperatures of around 26 °C and rainfall between 2000–3000 mm/ year, with a dry season between September and December (Baar 2004; Lauer et al. 1996; Bastos et al. 2002). Consequently, the potential natural vegetation is the evergreen tropical rainforest (Hueck 1966; Pires and Prance 1985). The main soils are Oxisols, Ultisols, and Entisols, characterized by an average pH of 4.5, low nutrient fertility, particularly in P and N, a low cation exchange capacity, and high aluminium saturation (Baena et al. 1998; Sommer 2000; Sommer et al. 2004).

2.2 Classification and distribution of degraded pastures

For the first objective, above-ground pasture degradation caused by the regrowing capoeira was classified and quantified. Satellite images are known to be an efficient and economical way of identifying land use classifications and detecting land use changes in the Amazon (e.g. Alves 2002; Vieira et al. 2003; INPE 2008). However, former land use studies based on satellite data are mainly used to distinguish forests from pastures or other main landscape units only. One reason is that bush-encroached pastures are not easily classified due to similar spectral characteristics in relation to forests. Other reasons are the high rate of cloudiness in the studied region and a sensor error of the Landsat 7 satellite, since May 2003. For these reasons this study worked additionally with QuickBird-2 data showing no data gaps and fewer clouds. Owing to the higher resolution (0.6–0.7 m) of the QuickBird imagery in relation to Landsat (30 m), it was easier to distinguish between different stages of above-ground pasture degradation. As the majority of capoeira shrubs and young trees reaches a soil cover of more than one square metre after one year, they must be detectible on QuickBird imagery. Therefore, it was hypothesized that different stages of above ground degrading pastures may be identified and the satellite imagery can be used as additional ground checks and references for Landsat land use classifications.

Landsat 7 ETM+ data (path 223/ row 61) of October 20, December 07, 2006 and August 04, 2007 were taken during the dry season. The failure of the so-called Scan-Line-Corrector (SLC) was eliminated by means of a procedure that reduces or eliminates data gaps by combining multiple images

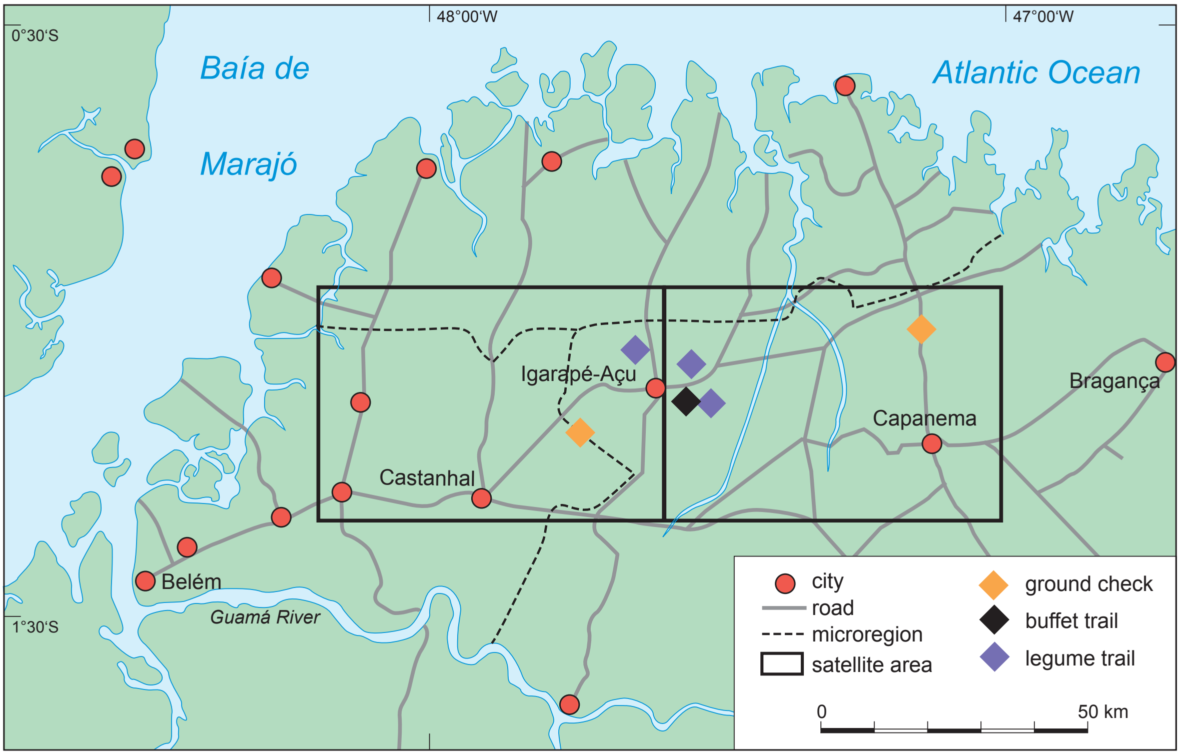

Fig. 1: Overview on the Bragantina region in the north-eastern Amazon, Northern Brazil, with the investigated satellite area (black), the locations of the QuickBird-scenes (orange rhombi), the buffet trial (black rhombus), and the three replications of the legume trial (blue rhombi).

of the same scene into one gap-filled image. Prior to this correction, cloud and shadow covering parts of the image are masked and the effects of different atmospheric compositions and differences in illumination direction and intensity are minimized by performing a radiometric adjustment on the images beforehand. Furthermore, the QuickBird images (June 23, 2004 and July 19, 2005) guarantee the appropriate application of training data, the most important step to perform a supervised classification (Lillesand et al. 2003; Richards and Jia 2006). By means of a training data set comprising spectral characteristics of each land cover class, a supervised classification was performed (Gangkofner 1996; Sabins 2007). The final classification result, including land use or rather cover map, was based on a sampling including the three Landsat images 2006 to 2007 (Krummel et al. 2008). The classification worked conservatively with an interval of 67–100% for detecting degraded unproductive pastures. A midrange-stage of degradation of 33–66% was also collected to guarantee a smooth transition between the first and third pasture site. During these ground checks a comparable number of intact pastures, slightly and heavily degraded pastures were approached and checked with imagery. On the other hand, up to 1 ha pasture plots of homogeneously degraded pastures of all kinds of categories were sought and taken as references. Altogether, 170 ha field verification sites were established during the 2007 dry season (October and November) in the municipalities of Igarapé-Açu and Capanema (Fig. 1).

2.3 Palatability of capoeira species and other common domestic tree species

Another result of a conducted grass-capoeira pasture elucidated that cattle did not evenly browse the capoeira but were rather selective on the plants (Hohnwald 2002). For instance, it was found that many members of the myrtle family (Myrtaceae) were hardly palatable while some spontaneous legumes and e.g. *Cecropia palmata* Willd. (Cecropiaceae) were entirely defoliated by consumption (Hohnwald et al. 2006). For this trial those obviously palatable capoeira species, which (i) provide high leafy biomass production, (ii) were abundant in capoeiras (Tab. 1), and (iii) thus easily accessible for smallholders were chosen and tested for its relative palatability against well-known woody forage legumes in a "buffet trial". In such a buffet trial, cattle can freely choose supplementary forage plants from a highly productive forage grass layer (e.g. SCHMIDT et al. 2001). Apart from *C. palmata*, the most interesting and tested capoeira species were *Attalea maripa* (Aubl.) Mart. (Arecaceae), *Phenakospermum guyannense* (Rich.) Endl. (Strelitziaceae), and the legumes *Inga edulis* var. *parviflora* Benth. as well as *Abarema jupunba* (Willd.) Britton & Killip (HOHNWALD 2002). Some other common domesticated, obviously palatable tree species were added in the trial that showed the same above mentioned criteria, in particular *Tithonia diversifolia* (Hemsl.) A. Gray (Asteraceae), *Mangifera indica* L. (Anacardiaceae), and *Racosperma mangium* (Willd.) Pedley (Fabaceae). The objective is the comparison of the relative palatability of these species, hypothesizing that they have the same palatability as well-known forage legumes.

The buffet trial was conducted at Igarapé-Açu (1°08'35"S/ 47°35'40"W; Fig. 1), where young individuals of each species were transplanted from a capoeira or as seedlings from the greenhouse on a well-established 0.53 ha *Brachiaria*-pasture. Twenty-five individuals of each species were planted in a 25 m² square paddock with 3 m distance to the next paddock. Paddocks were randomised in each block. Blocks were replicated eight times on the pasture (n=80 paddocks, 2000 plantlets). After one year establishing time, the pasture was grazed in the beginning of the rainy season (in February) by putting five oxen on the pasture for one week.

The height and radius of all available plants were measured before and after cattle access (n=1188), and the average right circular cylindrical volume (volume = $\pi * \text{radius}^2 * \text{height}$) was calculated in cm³ as an indicator of additional leafy forage biomass. Additionally, the number of the dead individuals was counted, before and after grazing.

2.4 Multi-purpose woody legume species under smallholder management

The traditional way to increase forage on tropical pastures is either the fertilization of the forage grasses or the plantation of multi-purpose legumes. Multi-purpose legumes offer extra forage biomass with higher protein contents than grasses while providing many other environmental services, e.g. N-fixation by the aid of its nodules, shadow, water preservation, nutrient pump etc. (GUTTERIDGE and SHELTON 1994; YOUNG 1989; VEIGA et al. 2000). Out of the huge pool of around 5000 known nitrogen fixing woody legumes, several hundred species have a major potential as promising multi-purpose woody plants and about 80 species play an important role for agriculture in tropical farming systems (HECHT 1979; SHELTON 2001; GUTTERIDGE and SHELTON 1994). For our experiments, the promising woody multi-purpose legume species *Cratylia argentea* (Desvaux) O. Kuntze cv. Veraniega (BRA 000167) (PIZARRO and CORADIN 1996; ANDERSSON et al. 2006a) and *Flemingia macrophylla* (Willd.) Merr. (THOMAS and SCHULTZE-KRAFT 1990; ANDERSSON et al. 2006b) were selected due to their good performances, environmental adaptations (dry seasons, acid soils), robustness, and the positive experiences in the region (HOHNWALD et al. 2006).

However, while forage legumes have proved their abilities in research trials, farmers have often experienced disappointing results. The reasons are often not understood yet the lack of perceived benefits and failure in technology and approach appear to be the main reasons (e.g. SHELTON et al. 2005). Poor performance is sometimes due to poor legume establishment and neglected management and too intensive use, probably adequate for forage grasses (e.g. HOHNWALD et al. 2005). This is also in the case in the dynamic smallholder system described above, in contrast, however, to intensive systems smallholders allow an extraordinarily long recuperation period of up to half-a-year afterwards, which may be favourable for the legumes. We suggest that, although legumes are completely browsed in such cases, the longer restoration times will compensate for that so that legumes will perform better under smallholder management than in intensively managed grass-legume systems

Testing this hypothesis, a typically managed smallholder pasture with high stocking rates but long restoration times (T1 = smallholder) was compared to an extensively managed pasture with low stocking rates and long restoration times (T2= fazenda) and an intensively-managed researcher-leaded pasture with low stocking rates and short restoration times (T3 = intensive). Pasture plots of 0.5 ha for each treatment were installed on well-established *Brachiaria*-pastures at three different farms (three blocks) around the city of Igarapé-Açu (Fig. 1). Six thousand seeds of each *C. argentea* and *F. macrophylla* were planted under greenhouse conditions in December 2005, in 0.5 l plastic bags of 50% organic matter and chicken dung, respectively. In the beginning of the rainy season 2006, legumes were planted on pasture plots

Table 2: The three tested pasture management systems.

Management type	Grazing days	Restoration days	Stocking rate AU	Total area ha	Area x Ø AU (=450 kg) kg	# of oxes (initially 350 kg)
Smallholder	7	56	1.0	4.5	2025	6
Fazenda	7	56	0.7	4.5	1418	5
Intensive	7	28	0.7	2.5	788	3

in alternating species lines of 1.5 m and 5 m distances to each other and were fertilised with 40 kg P_2O_5/ ha. As a consequence, each pasture plot consisted of 300 *C. argentea* and *F. macrophylla* plantlets, respectively (n=5400 plantlets). Grazing started in April 2006 and was carried out according to the different management systems shown in table 2. Animals were supplied with water *ad lib* and 50 g salt/head/day. When not on experimental plots, animals grazed on the farmers' pastures. As an indicator for legume performance the heights and number of plant shoots of around 60 plantlets per plot (n=1877) were measured before the subsequent grazing phase of the respective plot, i.e. in May 2006 and May 2007. Differences in legume heights and shoots were tested by using a mixed linear model-GLM procedure of SAS® version 6.11 (SAS Institute inc. 1990).

3 Results

3.1 Satellite images reveal a high proportion of bush-encroached pastures

Our satellite classification elucidated that 42% of the Bragantina region has been already converted into pastures, of which 14% were in a slightly and in an advanced stage of degradation, respectively (Fig. 2 a and b). Typical examples of the two degraded pasture classes are shown on photo 1 and photo 2. Sixteen percent of the rural landscape was classified as capoeira, 12% gallery forests, 13% as palm oil plantations, 14% as crop fields, and 3% others (Tab. 3). The results illustrate that the Bragantina region is still suffering from a serious agro-ecological problem of above-ground pasture degradation. The strong woody capoeira composition developed dur-

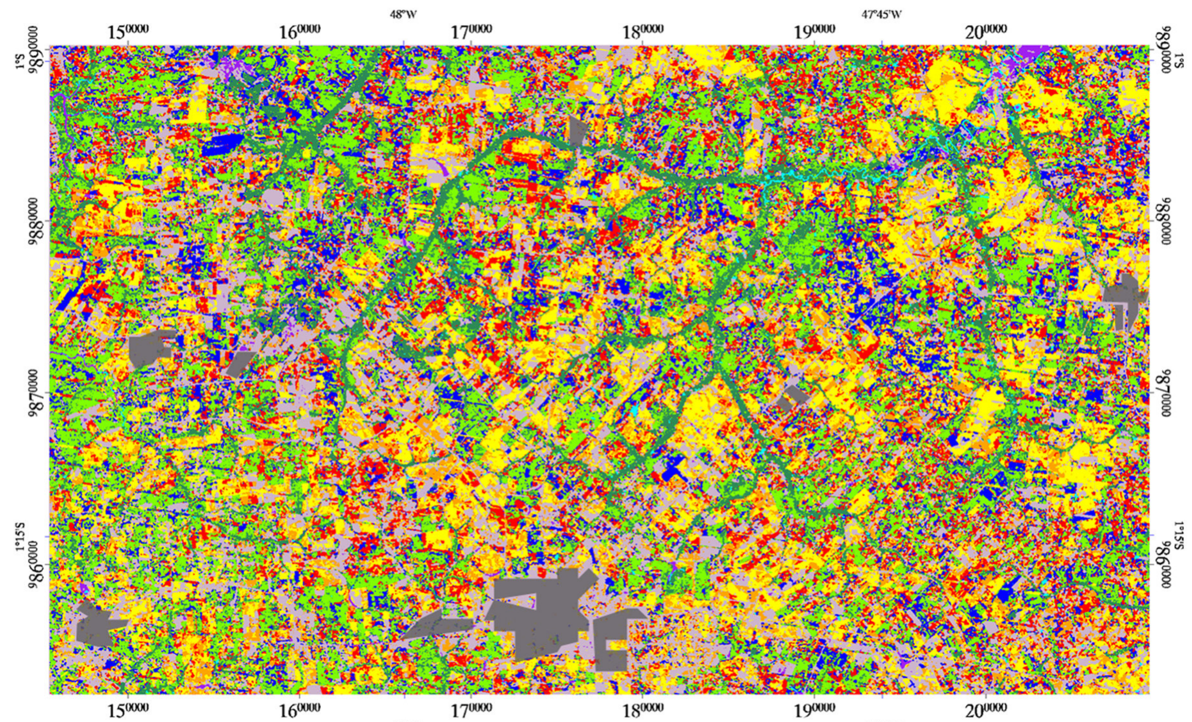

Fig. 2a: Land use classification focused on the differentiation of three pasture degradation stages: an example from the central Bragantina region in north-eastern Pará - western part (legend in Tab. 3).

ing centuries to withstand heavy human impacts of slashing and burning, and responsible for the sustainability of family based agriculture became the main agricultural problem on pastures.

The classification error matrix shows convincing consistency in most cases, with an overall accuracy of 89% (cf. Krummel et al. 2008). The most common misclassifications were related to slightly degraded pastures misclassified as advanced degraded pastures and *vice versa*. Some pastures of the third degradation stage were wrongly classified as oil palm plantations, some intact pastures as slightly or advanced degraded pastures, and some gallery forests as capoeiras.

Table 3: Proportion of land use classes in the Bragantina region with special emphasis on degrading pastures (with legend of Fig. 2).

Legend	Land use classes	ha	%
	intact pastures	68,959	14.22
	slightlydegraded pastures	69,066	14.24
	advanced degraded pastures	69,868	14.41
	total pastures	**207,893**	**42.87**
	capoeiras	77,093	15.90
	gallery forests	57,369	11.83
	total forests	**134,463**	**27.73**
	crops/ bare soil	69,286	14.29
	oil palm plantations	63,203	13.03
	swamps	2,043	0.42
	waters	7,459	1.54
	clouds	210	0.09
	cloud shadows	381	0.16
	Urban (separate layer)		
	total	**484,942**	**100.00**

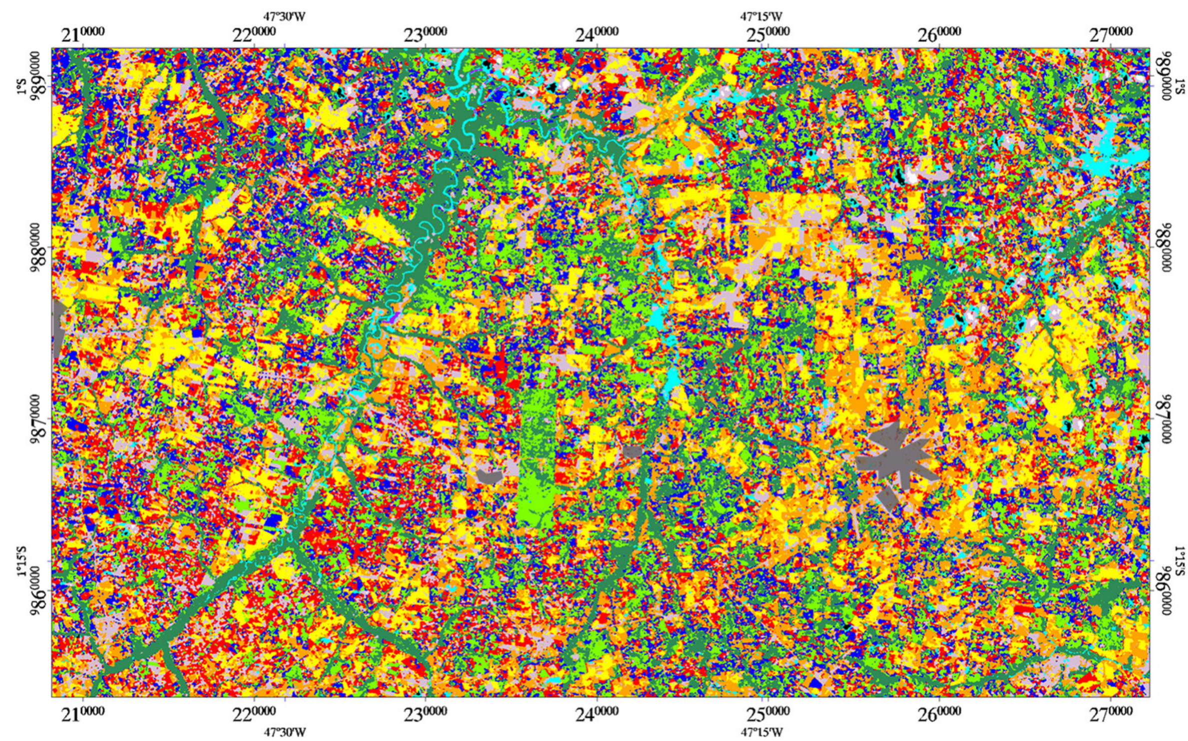

Fig. 2b: Land use classification focused on the differentiation of three pasture degradation stages: an example from the central Bragantina region in north-eastern Pará - eastern part (legend in Tab. 3).

3.2 Buffet trial

Most tested species have a comparable high palatability like the control legumes (Tab. 4). The tested plants can be categorised in three palatability groups: 1. very palatable= *C. argentea, C. palmata, T. diversifolia;* 2. palatable= *A. jupunba, M. indica, R. mangium,* and *I. edulis*, 3. medium palatability= *P. guyannense, F. macrophylla* (Tab. 4). However, *A. maripa* and *T. diversifolia* showed retarded growth and could not be classified due to the lack of sufficient biomass, there were, however, some observations showing that *T. diversifolia* rather belonged to the "very palatable" group, while *A. maripa* to the "medium". Results of the buffet trial reveal that most tested species are interesting supplementary forage plants and should at least be tolerated if not fostered on pastures, e.g. by pruning into an accessible height for cattle.

Transplantation and establishment of most species from a shady capoeira onto a pasture, already showing an advanced stage of soil depletion (compaction in 20 cm depth, low nutrient contents), were problematic, remarkably for *A. maripa*, *I. edulis,* and *C. palmata,* and cannot be recommended to farmers. However, leafy biomass from outside the pastures could be cut and carried to cattle from adjacent capoeiras, for instance during forage shortage of dry seasons.

3.3 Multi-purpose woody legume species on smallholdings

Significant differences in legume heights (Tab. 5) showed that both species developed significantly better ($p<0.05$) under smallholder management (T1) than in the other two treatments, with the exception of T3 of *F. macrophylla* in 2007 that reached the same median height as T1. During the whole experiment, *F. macrophylla* bushes were significantly higher and had significantly more shoots than *C. argentea* ($p<0.0001$), which can be explained by the high palatability of *C. argentea* in comparison to less palatable *F. macrophylla*. The number of *C. argentea* shoots did not differ between treatments also referred to the complete defoliation of that species during the grazing periods. Nevertheless, *C. argentea* was not selected out but showed also a significant growth in the experimental year ($p<0.0001$). In contrast, lesser palatability of *F. macrophylla* was reflected by the strong growth rates and significant increase in shoot numbers. Block effects of heights and shoots were all significant ($p<0.0001$) explained by the more fertile soils on farm 2 and the poorer soils of farm 3.

These results imply that both legumes are promising multi-purpose legume options for the Bragantina region, although the two species featured contrary characteristics: *C. argentea* showed better performances as forage supplement species indicated by its known excellent palatability (cf. Hohnwald et al. 2005) but showed poor biomass production for soil recuperation. In contrast, *F. macrophylla* was less useful as forage plant yet showed high biomass accumulation (litter, N-nodule fixation) for soil enrichment.

4 Discussion

Our consistently positive results of the buffet and the legume trial show that woody components (capoeira and woody multi-purpose legumes) could

Table 4: Average right circular cylindrical plant volume (volume = $\pi * radius^2 * height$) in cm³ before and after cattle grazing, losses in percent, number of dead individuals before and after grazing, 24 months after plantation (n=1188), arranged after biomass losses in percent.

Plant species	Family	before grazing in cm³	after grazing in cm³	losses in cm³	losses in %	# of dead before grazing	# of dead after grazing
Cecropia palmata	Cecropiaceae	683	84	599	86	8	17
Cratylia argentea	Fabaceae	2366	504	1862	72	5	11
Abarema jupunba	Fabaceae	540	222	318	58	4	10
Mangifera indica	Anacardiaceae	1133	474	660	58	2	5
Racospermum mangium	Fabaceae	7037	3679	3358	32	5	6
Inga edulis	Fabaceae	1067	831	236	22	9	10
Flemingia macrophylla	Fabaceae	6432	5223	1210	18	0	1
Phenakospermum guyannense	Strelitziaceae	1453	1293	159	10	2	2

Table 5: Mean height (in cm) and median number of shoots per plant plus standard errors (se) of *Cratylia argentea* and *Flemingia macrophylla* under three management systems: T1= smallholder, T2= fazenda, T3= intensive management (n=1877 height and shoot measurements, respectively).

	C. argentea in May 2006				*C. argentea* in May 2007			
	heights	se	shoots	se	heights	se	shoots	se
T1	67.2[a]	2.62	2.10[a]	0.21	105.2[a]	2.24	3.14[a]	0.18
T2	55.8[b]	2.68	1.67[a]	0.21	91.4[b]	2.24	2.76[a]	0.18
T3	46.8[c]	2.65	1.64[a]	0.21	89.8[b]	2.24	2.82[a]	0.18
	F. macrophylla in May 2006				*F. macrophylla* in May 2007			
T1	95.5[a]	2.56	7.77[a]	0.20	142.9[a]	2.24	10.69[a]	0.18
T2	89.8[ab]	2.56	7.28[a]	0.20	131.0[b]	2.24	10.17[b]	0.18
T3	84.1[b]	2.61	6.16[b]	0.21	145.6[a]	2.24	11.51[c]	0.18

[a, b, c] values within the same column with different superscripts, for each species separately, are significantly different at $p<0.05$ (Kruskal-Wallis test).

play a crucial role in the sustainability of smallholder pastures and contribute to forage supplement in the Bragantina region. Furthermore, woody components are excellent tools to classify and quantify different pasture degradation stages.

The degraded pasture percentage of total 28% is surprisingly high in comparison to other Landsat classifications of recent years, finding 22%, 25%, and 19% of pastures, respectively (Vieira et al. 2003; Wickel 2004; Puig 2005). However, as the problem is technically resolvable by the use of tractors, at least on fazendas, the amount of tree-dominated pastures might be quite dynamic.

The combination of using Landsat and QuickBird scenes as ground checks and training areas was an easy, cheap, and reliable tool to detect tree-dominated pastures so that our hypothesis has been accepted. A finer and more detailed classification of pasture degradation is technically possible but replication or transmitting to other regions in the Amazon might get complicated as other types of secondary vegetation will reflect different signals. Problems occur as pastures depending on the area do not evenly degrade but in a rather patchy manner so that clear class limits can hardly ever be drawn.

It remains unclear if our higher figures of pastures, compared to the other studies, are rooted in the unawareness of tree-dominated pastures of these authors or if a real tendency of increase pastures occurred in the region. Even so, for there is no clear tendency of pasture increase with time, taking the four studies as references (Vieira et al. 2003 - Landsat scenes from 1999; Wickel 2004 - Landsat from 2001; Puig 2005 - Landsat from 2002/2003; this study from 2006/2007), we suggest that the underestimation of tree-dominated pastures has had more effects on the result than a real pasture expansion. However, as pastures and palm oil plantations are obviously already dominating the region, dynamic land use change remains high, and a new era appears to have started – an era of pastures-and-oil-palm plantations.

On the other hand, the results elucidate that the prolific capoeira vegetation with its nutrient restoration abilities is still present and widely distributed on paddocks in the Bragantina region. Smallholders, intending to give up their cattle engagement, still run a chance on simply allowing the capoeira to grow through and let it collect nutrients for a subsequent cropping phase. Also, the preconditions to carry out the idea of grass-capoeira-legume pastures are still given on most smallholder properties.

We conclude from the results of the legume management experiment that the combined use of both legumes will fulfil both functions: improving forage availability along with soil fertility at the same time; in particular, as cattle may proceed from *C. argentea* to *F. macrophylla* in times of forage shortage, e.g. during prolonged dry seasons. Our results reveal that both legume species are promising options for smallholders as they perform well under flexible smallholder management. Exaggerated stocking rates for a short time are compensated by prolonged restoration times and sustain especially those legume species with slow establishment rates, like *C. argentea* (Hohnwald et al. 2005).

5 Conclusion: Refining the model of a grass-capoeira pasture for the Bragantina region

The lack of forage biomass on a grass-capoeira pasture and the palatability of the tested legumes and capoeira species lead us to the conclusion to combine the two ideas and to plant multi-purpose legumes on a grass-capoeira pasture – a grass-capoeira-legume pasture. Thus, we propose the following improvements of the Loker-model for the Bragantina region: as burning should be avoided due to its associated enormous nutrient losses and risk of uncontrolled fires (Mackensen et al. 1996; Kato et al. 1999), the capoeira should be alternatively mulched by choppers (e.g. Denich et al. 2004; Sommer et al. 2004; Bittencourt 2008). Multi-purpose legumes are separately sown under greenhouse conditions in January and planted along with the cassava onto the fields in July. The legumes are planted in three metres distances to each other and are supposed to replace unpalatable capoeira species while palatable trees are tolerated and semi-yearly pruned to an accessible height for cattle. Animal production starts in January when the cassava is harvested and the forage grass and legume layers are well established. After two years of grazing, the usual time to fatten oxen in the region, animals are sold and the capoeira fallow is closed. As farmers are usually familiar with the proposed techniques and the new agricultural system approach actually comprising less physical slashing work for them, there are no adaptation problems for smallholders to expect. Nevertheless, the system requires more knowledge, for instance of capoeira species, and implies some investment and know-how on the legume technology.

Silvo-pastoral systems will bring many ecological and conservation services, as trees will attract indigenous wild life, improve soils, and support hydrological and climatological eco-services (Sarmento 2007). Moreover, recent climatic models of the Amazon Basin foresee a significant warming and draining, peculiarly in the Eastern Amazon. For this century, they predict a probability of up to 70% of enhanced droughts and up to 30% probability for 50% droughts (Malhi et al. 2008). Reforestation is essential to detain the climate change since deforestation is said to be its main reason. As pastures already occupy almost half of the north-eastern Amazon, woody components on pastures like grass-capoeira-legume pastures or further silvo-pastoral systems become inevitable and will counteract the climatological change of the region.

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