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The Extractive Reserve System is championed as a win–win model of sustainable development in which rubber tappers serve to protect the forest while improving economic growth and resident well-being. Recently, reserves are being questioned in terms of their environmental sustainability, as many rubber tappers increasingly turn to market agriculture in times of economic duress and instability. This study explores land-use/land-cover change in six rubber estates within the Chico Mendes Extractive Reserve, using both remote sensing analysis and household surveys, and addresses the differences in deforestation by livelihood trajectories. A remote sensing analysis between 1986 and 2003 shows that some communities are close to surpassing the allowable limits of deforestation. Rubber tapping plays a less important role in livelihood strategies, as welfare is linked to non-extractive activities. Households pursue diverse livelihood activities including extractivism, small-scale market cultivation, animal rearing, and cattle production. The results suggest that land-use/land-cover change is highly dynamic in the reserve.

Keywords: Brazilian Amazon; extractive reserves; land use; rubber tapping; tropical deforestation

1. Introduction

Tropical deforestation is arguably the most significant type of land-use/land-cover change (henceforth, land change) underway globally, given its multi-scalar and multi-dimensional elements affecting a wide range of ecosystem services from landscape-level precipitation to river basin hydrology and to the functioning of the earth system, including global climate change (e.g., Myers, Mittermeier, Mittermeier, Da Fonseca, and Kent 2000; Watson *et al*. 2000; Steffen, Sanderson, and Tyson 2004; Bunker *et al*. 2005; Lambin and Geist 2006). No region of tropical deforestation has drawn more concern than the Amazon basin, especially the Brazilian Amazon. The Amazon remains a hotspot for tropical deforestation (Achard *et al*. 2002; Asner *et al*. 2005) with profound documented impacts on a full range of ecosystem to earth system concerns (Nobre, Sellers, and Shukla 1991; Salati and Nobre 1991; Laurance, Vasconcelos, and Lovejoy 2000; Laurance *et al*. 2002; Ferraz *et al*. 2003; Gash, Tani, and Bruijnzeel 2005; Houghton 2005). Deforestation follows the expansion of the logging and agricultural frontier, both increasingly driven by global markets (Faminow 1998; Mertens, Poccard-Chapuis, Piketty, Laques and Venturieri 2002), while traditional

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people struggle over access to land and resources (Schmink and Wood 1992). Pan-Amazon and especially Brazilian policies, therefore, have the challenge of balancing environmental concerns with land reform while ensuring economic growth and development (Hecht and Cockburn 1990; Smith 2001; Kainer, Schmink, Leite, and Da Fadell Silva 2003).

The Brazilian Extractive Reserve System (RESEX) is one form of land use and entitlement seeking this balance. Threatened by cattle ranching and large-scale agricultural projects, traditional extractivists in the region – those who live mainly off the extraction of non-timber forest products (NTFPs) such as rubber, Brazil-nuts, and hearts-of-palm – have fought for the legal recognition of their land rights. The RESEX was born out of the increasingly recognized need for sustainable development (WCED 1987; IUCN 1995), within the context of economic and social justice, particularly for Chico Mendes and the Rubber Tappers Union (CNS 1985). Under this system the government holds the title to the land, while extractivist associations hold concessions to its use. The RESEX, therefore, has two complementary goals: (i) the conservation of important ecosystems, such as forests, and (ii) the preservation of traditional extractive economies and cultures through sustainable development (MMA 2004).

Since its creation in 1990, RESEX has been championed by many as a win–win (sustainable development) model in which reserve residents conserve the forest in a form of sustainable use, which is expected to lead to economic growth and improved well-being (Murrieta and Rueda 1995). RESEX thus joins a litany of efforts worldwide to use ‘working preserves or parks’ to maintain forest cover and ecosystem integrity through maintenance of ‘traditional’ uses (Alcorn 1992; Gomez-Pomp and Kaus 1992; Terborgh and Van Schaik 2002; Tucker 2004; Zarin 2004). Recognizing that many forest lands are co-evolved landscapes (Alcorn and Lynch 1992; Clement, McCann, and Smith 2003), the win–win character of these efforts, especially regarding the material development of the peoples involved, remains an open question, with critics of parks citing problems of corruption, bureaucracy, political instability, and the further marginalization of the poor, among others (Terborgh and Peres 2002; Van Schaik 2002; Van Schaik and Rijksen 2002).

This concern is muted by some advocates of the RESEX who, in their attempt to legitimize the rubber tappers movement and alternative forms of development, may have overly romanticized both the rubber tappers and the main objectives of the extractive reserve model. Since his assassination in 1988, rubber tapper leader, Chico Mendes has himself reached almost mythic proportions, being described as an ‘ecologist’, a ‘rain-forest Gandhi’, an ‘eco-martyr’, and one of the ‘50 most important environmental thinkers in history’ (Gale 1998; Palmer 2002; Maxwell 2003; Revkin 2004). To others, he was a hard-hitting communist party labor leader and a ‘radical political militant’ (Hecht and Cockburn 1990; Maxwell 2003). Such extreme descriptions are not limited to Chico Mendes but to the rubber tappers themselves and even to descriptions regarding the sustainability of the RESEX model.

A polemicized debate concerning the sustainability of the RESEX model has emerged with little common ground between advocates and critics. Proponents argue that extractive reserves serve to lower deforestation rates, protect biodiversity and ecosystem integrity, and as buffers preventing or inhibiting land-cover destruction by fire, while preserving the culture and ensuring the economic livelihood of traditional forest-dwelling people (Allegretti and Schwartzman 1989; Anderson 1990; Hall 1997; Nepstad *et al*. 2006). Brazilian environmental policy makers, environmentalists, and the National Council of Rubber Tappers, often backed by financial support from the international community, have favored this type of ‘green’ development and press for the creation of extractive reserves and other conservation units to cover 10% of the Brazilian Amazon, an estimated 500,000 square kilometers, or roughly the size of Spain (Amazon Press 2001).[1]

By February 2008, 39 federal extractive reserves and 25 state extractive reserves, covering an area of over 12 million hectares, had already been created in the Brazilian Amazon (Gomes 2009).

Critics question the reserves in terms of their economic, social, and environmental sustainability (Fearnside 1989; Browder 1992). Specifically, the reserves have been criticized on issues of biodiversity – that extractivists and extractive activities may have a negative predatory affect on both flora (Moegenburg and Levey 2002) and fauna (Oliveira 1991; Peres 2005). Furthermore, some economists suggest that, historically, extractivism has not been able to alleviate poverty, and this exclusive kind of economy will eventually disappear, as economically valuable forest products inevitably end up being grown on plantations, at less cost and of higher quality (Homma 1989; Browder 1990; Homma 1994).

Much of this debate is theoretical in nature, lacking systematically collected socio-economic data collected on extractive reserves. More recent studies in the Chico Mendes Extractive Reserve (CMER) have tried to ground these arguments by focusing on field-based data collection and analysis of both livelihood trajectories and the ecological impacts of such livelihood decisions by residents of the CMER (Sassagawa 1999; Wallace 2004; Ehringhaus 2005; Vadjunec 2007; Gomes 2009).

A deeper understanding of this debate, aided by the results of research being carried out in the CMER, is increasingly important because criticisms surrounding the RESEX system have been re-ignited. In August 2005, runaway fires ravaged the CMER for 3 weeks before being contained (Amigas da Terra 2005). The fact that it was the rubber tappers themselves who accidentally started the fires outraged much of the public, sparking tensions by some regarding the legitimacy of the entire RESEX model. As a result, the reserve's ability to perform as a conservation unit is currently under fire in the Brazilian national press, with a few critics accusing many RESEX parks as a 'conservation lie' (Brito 2005a), grounded in 'pseudoscience' (Olmos 2006), and offering as 'proof' examples of (non-Federal, non-RESEX) state-run extractive reserves in Maranhão or Rondônia, where between 60 and 100% of forest cover has already been lost (Brito 2005b).[2]

The CMER has witnessed a substantial growth in pasture and small-scale cattle ranching triggering deforestation in some areas (Gomes 2001) although the scale of deforestation is low compared to the surrounding region. A 3% total forest-cover loss between 1986 and 1999 was recorded in the reserve by two remote sensing analyses (CNPT 1999), one of which suggests that some communities in the CMER are close to reaching their allowable limits of deforestation and would reach them by 2003 (Sassagawa 1999). While variation among rubber tapper communities is addressed in this last assessment, less attention has been given to explaining the reasons why such variation exists (Gomes 2001, 2009) and virtually no attention has been given to assessments of deforestation as associated with the variation in community livelihoods in the CMER. In fact, considerable variation in community economies has emerged in the reserve, with some communities focused more on extractivist activities and others more on agriculture and cattle rearing.

This article compares deforestation in the communities in the CMER with their economic orientations. This exercise is important because it helps to illuminate the relative impacts on forest conservation and household income of different human-environment conditions existing in the reserve, thus providing insights about the ideal conditions for sustainability of the CMER, considering its dual purposes of forest conservation and sustainable development (economic growth and resident well-being). In order to explore this relationship, six communities are examined in the CMER, four of which were projected to surpass their legal deforestation limits by 2003. Using remote sensing and household surveys, this study asks the following sub-questions:

(1) What are the land-use practices in the six communities and how are they changing?
(2) What are the amounts and rates of deforestation and secondary regrowth within the six communities between 1986 and 2003?
(3) Have any of the six communities surpassed allowable deforestation limits within the reserve, thus compromising the reserve's sustainability as a conservation unit?

2. Study area

2.1. Chico Mendes Extractive Reserve

The CMER, located in southeastern Acre (also known as the Alto Acre Region), is the most famous of all the RESEXs. It was created on 12 March 1990 by Federal decree, comprises 970,570 ha, and is located approximately between latitude 10°05′41″ S and 11°00′00″ S and longitude 67°56′10″ W and 69°48′22″ W (Figure 1). Approximately 12,000 people (about 2000 households) live within 46 different *seringais*, or rubber tapper estates, within the reserve (Feitosa 1995). The BR-317 highway runs along the eastern and southern boundaries of the reserve, connecting the capital of Rio Branco to Acre's other major urban centers of Xapuri, Brasiléia, and Assis Brasil and connecting Brazil to both Peru and Bolivia. The more isolated regions of the reserve can be accessed by the Acre, Xapuri, and Iaco rivers.

The CMER is, for the most part (73%), an open tropical forest biome high in both palm and bamboo species diversity with an average annual rainfall of 2200 mm, a mean temperature of 26°C, and a marked dry season (from May to August) where average

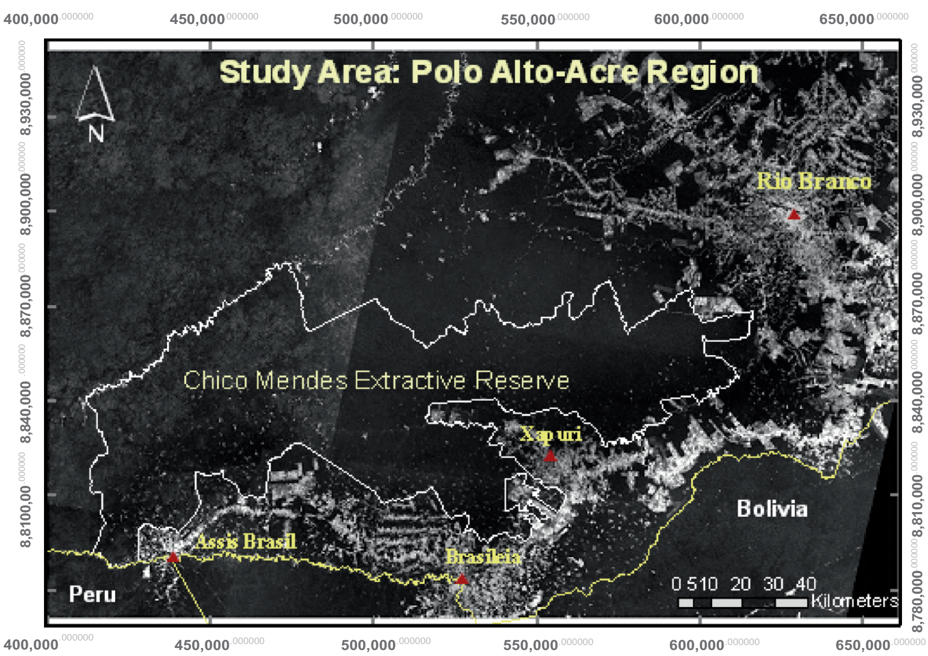

Figure 1. Study area: The Chico Mendes Extractive Reserve (CMER).
Source: Vadjunec (2007) using Landsat TM Imagery (2003) and ZEE base maps.

temperatures climb to about 38°C. The remaining 27% of the reserve is classified as dense tropical forest, which can mainly be found in the municipality of Brasiléia (CNPT 1999). This type of forest is often richer than open tropical forests in many key extractive species, such as *açai* and the Brazil-nut tree, thus providing some communities with inherently greater extractive potential. Topography of the region is slowly undulating, or 'hilly', and elevation varies between 100 and 300 m. In general, the reserve is dominated by a mix of mainly eutrophic and dystrophic soils, which, according to state authorities, provides workable soils and marked agricultural potential with the adoption of proper management practices (ZEE/AC 2000).

Although the reserve's title is held collectively by the reserve's associations, individual resource parcels are given to each household, based on a traditional land-use system known as the *colocação*, where the emphasis is on resources in the parcels, not on the land itself. A typical *colocação* contains the rubber tapper's house and other farm buildings, water well or small creek, patio garden, fruit orchard, agricultural plot, and pasture, if any. Historically, the most important asset in a *colocação* is the number of *estradas de seringa*, or rubber trails, held by each household. A household does not hold *de jure* title to the land but instead possesses the right to use the resources found within the *colocação* and rubber trails (mainly Brazil-nut and rubber trees, historically holding the most value).

At the reserve's creation, each rubber tapper was guaranteed at least three rubber trails, which is estimated to be roughly equivalent to 300 ha, although some families have more or less after trading, buying, or dividing up properties. In most *seringais* there is no communal forest as in a traditional common property regime; all forest is claimed by some household or another. The Utilization Plan (UP) for the CMER, which was made by the rubber tappers themselves, sets the allowable deforestation limits at 10% of the *colocação*, or theoretically 30 ha, with 5% (or 15 ha) allowed for pasture conversion. The nature of the *colocação* makes it difficult to map as rubber trails often intersect and overlap. It is important to note that households do not have traditional geometrical plots that are easily mapped and bounded. Furthermore, the CMER is a common property system where enforcement and regulation occurs mainly through the social organization at the community level. As a result, most monitoring of the 10 and 5% rules occurs at the community level, instead of the household level, if at all (Sassagawa 1999; Gomes 2001; Ankersen and Barnes 2004). Recently, the efficacy of the reserve has been questioned due to the expansion of small-scale cattle ranching within the reserve (Gomes 2001). In order to understand the controversy surrounding this recent land-use and livelihood change, it is important to look into the past. In Section 2.2, we discuss the history of rubber in Acre, resulting in the CMER today, and the changes in land use currently underway.

2.2. Land-use history and livelihood trajectories among rubber tappers in Acre

Starting with the rubber boom of the late nineteenth century, the state of Acre has had a long and varied history of rubber tapping and latex production (Barnham and Coomes 1996). By the late 1880s, the rubber trade was so economically important to the local, regional, and global economies that, accordingly (Hecht and Cockburn 1990, p. 80; Stokes 2000, p. 232), Acre was claimed to be one of the most valuable and important pieces of commercial real estate on earth, where at its peak in 1912 was exporting approximately 1200 tons a year to French, Belgian, British, and American firms (Coêlho 1982, p. 68).

This booming economy required many workers in a place where populations were sparse, the landscape was unforgiving, and the labor supply was scarce. As a result, the poor peasants from the drought-stricken areas of the Brazilian Northeast were encouraged by the Brazilian government to migrate to the rubber territories of the Amazon. In the drought of 1877 alone, an estimated 100,000 Northeasterners migrated to the Amazon region (Hecht and Cockburn 1990, p. 80). The rubber barons supplied the rubber tappers with trade goods, food, work supplies, and even the cost of their passage on credit, thus keeping the tapper indebted to continue tapping rubber for a relatively low price. Rubber tappers were regularly discouraged and even banned from practicing agriculture in their *colocação*, resulting in both the protection of precious extractive species and historically low deforestation rates while keeping the tappers dependent on the rubber barons and middle-men who delivered supplies.

The first rubber bust occurred in 1915 with the development of the Southeast Asian rubber plantations, when rubber exports for the whole of Amazonia fell to just under 30,000 tons annually (Coêlho 1982, p. 70). Not only was the cost of rubber production lower in Asia, Asian plantations also received a better price for a higher quality product, thus making it difficult for Brazilian-based firms to compete. By 1932 the market all but bottomed out, with the whole of Amazonia producing less than 5000 tons of rubber annually (Dean 1987, p. 169).

The second and short-lived rubber boom came with the advent of World War II and an urgent need for latex among the United States and its allies (Corrêa 1967; Martinello 1998). The Brazilian government was called upon to triple its latex production, creating the 'Rubber Reserve' and calling for *soldados de borracha*, or rubber soldiers, to fulfill their patriotic duties, offering up promises of a soldier's respect as well as a pension (only recently realized) in return for their rubber tapping services. By 1947, the US and Brazilian governments had pulled funding for the 'Rubber Reserve', and once again, the Amazonian rubber economy went bust, causing many rubber barons to abandon their rubber estates, leaving rubber tappers to fend for themselves.

While many rubber tappers fled to Acre's urban centers, many tappers stayed in the abandoned rubber estates supplying local and regional markets with latex (otherwise banned for importing to Brazil) and engaging in hunting, Brazil-nut collecting, and subsistence farming. The rubber tappers were left alone until the 1970s when the military government officially 'opened' the Brazilian Amazon for development. In Acre, this new development policy often led to violent land conflicts between rubber tappers and cattle ranchers, where rubber tappers were evicted and former rubber estates were cleared by cattle ranchers. It was under the context of such conflicts, along with increasing environmental concerns, that both the CMER and the entire RESEX system were created (Allegretti 2002).

According to a reserve-wide study completed immediately following the reserve's creation, rubber was the main source of income for residents of the reserve, representing 44.7% of the total household income while 24.6% of the household income came from Brazil-nut collection (in other words, almost 70% of a household's income was derived from NTFP extraction) (Feitosa 1995, p. 70; see also CNS 1992). Agricultural production represented 21% of the household income while small animal breeding and cattle rearing represented 4.8 and 4.2% of the total income, respectively (Feitosa 1995, p. 70). At this time, not only was rubber production the most important economic activity, the CMER produced more rubber than any other extractive reserve, producing on average 714 kg of rubber per family per year (Feitosa 1995, p. 70).

Ironically, in the mid-1990s, just as the rubber tappers themselves were gaining the long overdue recognition they deserved and as the CMER was being formalized, Brazilian policies ended the forced import bans and national subsidies placed on rubber. The rubber tappers finally gained land security, but at the same time lost many of the protections and incentives placed on their main source of livelihood. They also, during this time, gained autonomy to make their own land-use decisions. As a result, many rubber tappers have abandoned latex production altogether and are increasingly drawn to small-scale agriculture, animal husbandry, and even cattle production, resulting in the deforestation of concern within the CMER.

With the creation of the reserve came the long overdue recognition and inclusion of rubber tappers in Amazonian development policy. On the one hand, rubber tappers are faced with long-term market challenges regarding latex production and other NTFPs. On the other hand, with the creation of the reserve, they also have increased road access and therefore opportunities to participate in more diverse markets. The dominant market opportunities available in Acre, despite the attempts of the pro-forest government to build a sound sustainable development policy, unfortunately, are often not based on sustainable strategies but instead are influenced by local and regional economies operating outside of the reserve, which privilege cattle, and to a lesser extent, agriculture, over rubber and NTFPs. Overall, cattle ranching is now one of the most important economic activities in Acre and contributes more than 60% of the state tax revenue (Valentim *et al*. 2002). Furthermore, recent studies suggest that smallholders are responsible for roughly 62% of the new deforestation in Acre (Elia 2005; Barreto *et al*. 2006).

Activities of large holders are increasingly constrained by the large amount of protected areas in the region. This constraint, however, provides new opportunities for historically neglected smallholders to participate in these new market economies. As a result, extractivists are increasingly turning to more intensive land uses, such as market agriculture and cattle raising.

This brief overview of land-use trajectories among the rubber tapper population points out the reality that the political economic conditions under which the original rubber tapper land holdings and economic livelihood orientations were established may no longer exist. Many of the rules and regulations applied to their *seringais* remain, however, based on the assumption that the extractive reserve model can improve resident well-being while protecting the majority of the forested area – the win–win solution.

3. Methods

3.1. Site selection

Research was carried out in a total of six rubber estates within the two municipalities of Assis Brasil and Brasiléia (three estates each) of the reserve (Figure 2). The base characteristics of each rubber estate are provided in Table 1. Communities were chosen with the help of the municipal-level reserve associations based on the following criteria:

(1) Rubber estates were open and inviting to outside research. This was an important factor as the reserve is considered Federal property and outside research requires an invitation from the communities and a research license from the National Centre for the Sustainable Development of Traditional Populations (CNPT).
(2) Among those rubber estates chosen by the associations, estates were stratified based on perceptions of the reserve leaders on traditional extractive orientation versus non-traditional market orientations.

3.2. Remote sensing analysis

Our remote sensing analysis follows from a collaboration between researchers with different research objectives and, in one case, study sites. Therefore, satellite image analysis was

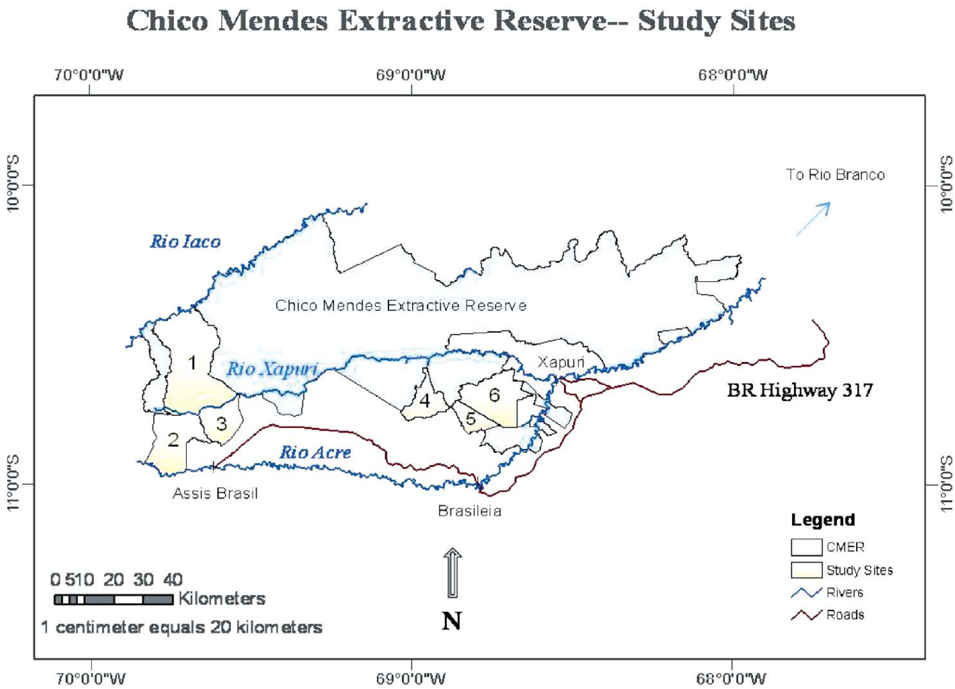

Figure 2. Location of the study communities within the CMER.
Source: Vadjunec (2007) based on maps from CNPT (2000), Sassagawa (1999), and ZEE/AC (2000).

Table 1. Characteristics of the study sites.

	Brasiléia			Assis Brasil		
	Porongaba	Filipinas	Humaitá	Paraguaçu	São Francisco	Icuriã
Estimated number of households	26	72	32	40	73	72
Number of households surveyed	17	26	19	20	19	29
Average family size	4.82	6.96	5.56	8.15	5.15	4.61
Average holding size (ha)	429.00	608.00	432.00	560.00	416.00	300.00
Total area seringal (ha)	8,937	29,908	14,487	19,511	29,933	64,405
Forest canopy type	Dense	Dense	Dense	Dense/ Open	Open	Open
Impact by division of watershed	No	No	No	No	No	Yes
Main form of transport	Road	Road	Road	Road	Road	Water/ road
Distance from community base to nearest urban center (km)	23	36	30	10	22	75
Livelihood emphasis	Cattle/ NTFP	NTFP	Cattle/ NTFP	Cattle/Ag	NTFP/ Ag	Cattle/ Ag

carried out on the footprint level for the *Alto Acre* region (10 scenes). LANDSAT TM and ETM+ images were obtained for 1986, 1992, 1996, 1999, and 2003 for Path/Row 02/67 and 03/67 (Image Source: Tropical Rain Forest Information Center of Michigan State University). Chronic cloud and haze problems common to the region required that the image synchronization match the short dry season, between mid-June and early September rather than more narrowly circumscribed dates. We started our time series in 1986 in order to get a glimpse of land use and land cover *before* the reserve was created and used subsequent years to see patterns in change, but limited our timeframe to 2003 in order to match our remote sensing data to our survey data, thus capturing more specific explanations of land-use and land-cover change at a particular point in time.

Ground data were collected between October 2003 and August 2005 for image georeferencing, as well as over 200 additional training/ground truth samples of various land-cover types. A training sample protocol was developed based on the specific ecology and land uses/land covers of the region and a training sample data base was created, including information on the geographic coordinates of the sample using a Global Positioning System (GPS), the land-use/land-cover type, sketch maps, and digital photos. We also collected brief land use histories given by the land owners to aid in the development of training sample data over various time frames (other than 2003). Given the resolution of our imagery (i.e., 30 m), samples were limited to areas 1 ha or greater.

Geometric rectification with a linear first-order polynomial fit was carried out on the 2003 images based on ground control points collected in the region using a GPS, using roads and intersections, and when a good geographic distribution was necessary and roads were lacking, both rivers and waterways. All resampling was done using a nearest neighbor resampling algorithm. The 2003 images were then used as a base to which the remaining scenes were resampled. On average, 12 ground control points (GCPs) were used for each image, with at least one point in each quadrant of the image, resulting in a root mean square error less than 0.5 pixels (or <15 m) in each case.

In order to compare image brightness values across scenes, it is necessary to correct for variations in brightness (or raw digital numbers or DN) values caused by differences in sensor calibration and in solar illumination, along with atmospheric conditions, such as Rayleigh scattering and haze (Green, Schweik, and Randolph 2005). Various exploratory methods were employed, and the best results were achieved with a radiometric calibration and dark subtraction (ATCORR) model developed by Green, Schweik, and Hanson (2002). Although this method helped to clean up the images in general, it did not clear up all atmospheric problems, particularly scattering effects on the 1992 02/67 image.

We adopted a hybrid unsupervised/supervised approach, which allowed us to create a more ample classification schema, even in years where training sample data were lacking. The entire classification process was based on methods developed at the Anthropological Center for Training and Research on Global Environmental Change/Indiana University (ACT/IU) and completed using ERDAS Imagine 8.7 (for complete detailed methods see Ludewigs 2006; also Brondizio 1996; Futemma and Brondizio 2003; Moran and Ostrom 2005). To ensure consistency, each image was classified and reviewed by at least two of the three authors.

An unsupervised classification was carried out on each image using a clustering algorithm to define land-cover classes based on spectral statistics with a standard number of 100 classes, 12 maximum iterations, and a convergence threshold of 0.95. Our 100 classes were gradually collapsed into 12 classes: dense forest, open/bamboo forest, initial secondary succession, intermediate secondary succession, pasture with trees, managed ‘clean’ pasture, unmanaged ‘dirty’ or ‘scrubby’ pasture, agriculture/bare soil, high-density urban, water, cloud, and cloud shadow (see Table 2 for description of classes). Class assignment involved three assessments: (i) visual interpretation of the image sequence (geographically linked) using expert knowledge and vectorized ground data and land-use histories collected in the field to guide our decisions regarding class ownership, and analysis of the spectral behavior of individual pixels belonging to known classes using a spectral profile tool; (ii) comparative analysis of the spectral behavior of the signatures for each of the 100 classes as well as

Table 2. Land-use classification schema.

ID	Class	Description
1	Dense tropical forest	Dense, closed tropical forest common to the region
2	Mixed open/bamboo forest	Open semi-deciduous forest intermingled with patches of bamboo and/or palm species
3	Secondary succession 1	Herbaceous, seedling, and sapling vegetation up to 5 m high, typical of agricultural land left to fallow or non-managed pastures
4	Secondary succession 2	Intermediate secondary stage with woody vegetation up to 15 m high, closed canopy
5	Pasture with trees	Managed pasture intermingled with trees
6	Managed clean pasture	Managed clean pasture, open grasslands with substantial green cover
7	Tall grass/wetlands	Tall grass/wetlands, lush green vegetation typical of areas with poor drainage or grassy wetlands
8	Agriculture/bare soil/ overgrazed pasture	At peak of dry season, areas lacking green vegetation cover, and/or showing patches of bare soil
9	High-density urban	Presence of asphalt and human-made surfaces with high reflectance (found outside of reserve only)
10	Water	Rivers, creeks, ponds, and other water bodies
11	Clouds	Cloud
12	Cloud shadow	Cloud shadow

groups of similar classes using the signature mean plot module; and (iii) the interpretation of unsupervised classes based on their spectral seperability statistics generated using a transformed divergence module.

Based on these criteria, the initial 100 classes were individually analyzed and assigned, with the help of the vectorized ground data and land-use histories we collected in the field, to a final classification schema, spectrally similar classes were merged with like classes, while others, such as those representing noise, were eliminated altogether from the classification. Due to the large number of initial classes, this was done in several stages producing a series of intermediary signature files for each year: thus, a 100-class signature file might be reduced to 60 classes, then 30, and once again until the final desired 12 classes had been reached. In order to ensure maximum spectral seperability of our classes, steps (i)–(iii) were completed and evaluated various times throughout the intermediary stages.

The final signature files representing 12 land-use/land-cover classes for each image constituted the input for a supervised classification using a probability-based maximum likelihood algorithm. After classification and evaluation, the classes were further reduced to a more simple and realistic classification schema given the constraints with such a long image sequence: Forest, Secondary Succession, a combined Agricultural Class (i.e., pasture, agriculture, bare soil), Water, and Cloud/Shadow. Aggregation helped eliminate sources of error among our anthropogenic classes, in particular, given that all images correspond to the dry season, when vegetation is commonly under hydrological stress.

To deal with common problems caused by atmospheric scattering due to cloud-cover problems in our 1992 image specifically and misclassifications and confusion caused by other anomalies (e.g., tree shadow and natural bamboo 'die-off' in one instance), post-classification techniques, such as a 3×3 kernel filer, and to a lesser extent, polygon filling, were used in some instances and in specific area of interests (AOIs), followed by careful inspection and the visual comparison of problem areas with the original bands geographically linked to the filtered image.

An independent hold-out sample of roughly 150 ground reference points was digitized into polygons and used in an accuracy assessment for both the 02/67 and the 03/67 footprints for our 2003 images (representing both 895 and 1264 pixels, respectively). In both instances, we achieved an accuracy level of 85% (p-value of 0.05).

Land-cover transition matrices were generated using a matrix or cross-tabulation module. Starting with the 1986 and 1992 images for each footprint, the matrix module was run successively adding each year in the sequence until a final transition matrix representing all years between 1986 and 2003 was complete. These transition images follow the state of any given pixel and its change from year to year. Separate transition matrices were produced to track deforestation, secondary regrowth, and a final matrix that attempted to capture the swidden/fallow cycle within each rubber estate, resulting in six final images, three for each footprint. Given uncertainties due to the spectral similarities between anthropogenic land uses as well as the problematic nature of having such a long (18 years) timeframe, pasture and cultivation classes were aggregated together to minimize classification error. Our transition matrices, therefore, used a simple forest–non-forest–secondary forest classification, thus minimizing the chances of error common between anthropogenic classes. As a result, it is impossible to distinguish through imagery analysis whether any of these rubber estates have greater than 5% of their allowable area in pasture, focusing instead on the efficacy of the 10% rule. Lastly, digital boundaries of the six *seringais* were then used to create masks producing 18 final images (capturing deforestation, regrowth, the swidden/ fallow cycle) for each community, allowing the calculation of the rates and amounts for each transition type between any given time period.

3.3. Household surveys

A total of 130 household interviews were completed within the six rubber estates between March 2004 and December 2004 by two of the authors and two field assistants in conjunction with a local non-governmental organization, the Group for Research and Extension in Agroforestry Systems in Acre (PESACRE). As often as possible, the interviews were completed with both the male and the female head of the household. Each interview was conducted in Portuguese, took about 3 hours to complete, and contained open-and close-ended questions regarding specific land use, production and sale of agricultural and extractive products, small animal and cattle production regarding production and yields for the year previous (2003), as well as household characteristics and history, and questions regarding the rules (both formal and informal) and management of the reserve, the history of the household's involvement in the rubber tapper's movement, and the social organization within each *seringal*, or rubber estate. Additionally, since many households operate on a mainly subsistence or recently transitioning mixed-subsistence and market livelihood system, we constructed a livelihood index to show what we feel is a more realistic picture of overall economic development and well-being. The index totals the presence or absence of 30 social-, economic-, and health-related development indicators (e.g., overall house construction, possession of important household appliances, agricultural equipment, access to an electric generator or other power source, water pump or well, access to safe drinking water or water treatment, trash and sewage disposal, accessible healthcare and education, mode of transportation, and overall satisfaction with the reserve).

Although the original intent was to choose households at random, difficult access and incomplete residency lists caused us to adopt a more opportunistic sampling strategy. Few roads exist in the reserve and some communities required a 3-day walk to reach. The only residency list available to use was outdated and, furthermore, was compromised by lack of information on households that are not officially members of the associations. Sometimes outsiders and non-members of the movement have purchased land, often illegally; they therefore may not be registered residents, but they no-doubt bring different land-use practices and economic orientations to the reserve.

Of the 130 households selected, 65 are involved in the government-sponsored environmental program *ProAmbiente,* which, although still in initial phases, proposes to pay small producers for environmental services. These households are officially recognized by and participate in the municipal-level extractive associations. These households were selected through a series of open public meetings held by the Rubber Tapper's Union to generate interest in *ProAmbiente*. The remaining 65 households participating in this study were chosen based on maximizing the geographical distribution of households selected within each community to the greatest extent possible, and with the help of key informants, emphasis was placed on representing the range of households involved in the various extractive/non-extractive activities that were brought to light in our initial community meetings (i.e., cattle, extractivism, agriculture, or a mix of activities). After 2 years of field experience, we estimate that 40% of the total households were interviewed in each of the study sites.

4. Results

4.1. Remote sensing results

Seringal Humaitá had the largest percentage of total area deforested by 2003, totaling 9.20% of the *seringais* (Table 3). Porongaba and Paraguaçu fell between (7.84 and 6.20%, respectively). Filipinas and São Francisco had the next lowest amounts of deforestation (3.80 and 4.93%, respectively). Lastly, Icuriã had the lowest total percent deforestation (3.58%) among all the six rubber estates.

Deforestation rates were on average highest during the initial 1986–1992 time period, accounting for between 17 and 39% of the total area deforested by 2003, averaging approximately to 24% of the total area deforested per *seringal.* This period was marked by extreme changes in the lifestyles of rubber tappers, including part of the initial violent conflicts between rubber tappers and cattle ranchers and the subsequent creation of the reserve in 1990, followed by the discontinuation of rubber subsidies that occurred in the 1990s. The periods between 1992–1996 and 1996–1999 indicate a general overall drop in deforestation rates within each of these six estates. An overall drop in deforestation rates during this time frame was also observed elsewhere in the region (Ludewigs 2006). This overall drop in deforestation rates is perhaps attributable to the initial optimism of the rubber tappers in securing the reserve, initial international funding and support, as well as the end of violent land conflicts throughout the region. Between 1999 and 2003 this trend changed toward more deforestation, for the most

Table 3. Percent deforestation in six *seringais* from 1986 to 2003.

	Porongaba	Filipinas	Humaitá	Paraguaçu	São Francisco	Icuriã
Forest (2003)	91.79	96.65	92.16	93.80	95.04	96.41
Deforestation (1999–2003)	1.82	0.97	1.80	0.78	0.64	0.98
Deforestation (1996–1999)	0.69	0.57	1.07	0.67	1.42	0.67
Deforestation (1992–1996)	2.06	0.78	2.05	0.96	1.03	0.60
Deforestation (1986–1992)	2.06	0.67	3.59	3.00	1.55	1.10
Area deforested (1986)	1.12	0.81	0.69	0.79	0.29	0.22
Total % deforested	7.84	3.80	9.20	6.20	4.93	3.58

Table 4. Percent secondary succession in six *seringais* from 1986 to 2003.

	Porongaba	Filipinas	Humaitá	Paraguaçu	São Francisco	Icuriã
Secondary succession (1999–2003)	0.72	1.03	0.97	0.36	0.59	0.55
Secondary succession (1996–1999)	2.57	1.42	1.56	0.13	0.26	0.11
Secondary succession (1992–1996)	0.49	0.65	0.49	0.15	0.21	0.27
Secondary succession (1986–1992)	0.30	0.42	0.24	0.13	0.21	0.32
Area in secondary succession (1986)	0.57	1.10	0.33	0.45	0.60	0.22
Total % secondary	4.65	4.62	3.59	1.22	1.87	1.47

part, with the exception of São Francisco, which continues to see a drop in deforestation rates. Contrary to prediction, however, none of the study areas have surpassed the allowable limits of deforestation as set by the 10% rule in the UP.

Transition matrices following secondary succession between the 1986 and 2003 period further reveal variations in land-use trajectories and schemas between households within each of the six communities (Table 4). Porongaba and Filipinas had among the highest total percentage of area in secondary succession by 2003, with 4.65 and 4.62%, respectively. Seringal Humaitá, with the highest percentage of total area deforested, also had one of the higher percentages in secondary succession by 2003 (3.59%). In general, the *seringais* located in the municipality of Brasiléia have considerably higher rates of secondary succession than their counterparts in Assis Brasil (Paraguaçu 1.22%, São Francisco 1.87%, and Icuriã 1.47%). Filipinas, with the second lowest amount of deforestation, also had the second highest rate in secondary succession (4.62%), while São Francisco had both a low rate of deforestation and a much lower rate of secondary succession (1.87%), suggesting different land-use decisions and intensification among all rubber estates.

Lastly, a final transition matrix was made for each of the six communities to capture the swidden/fallow cycle used among small-scale agriculturalists in Amazonia (Moran 2000; Ludewigs 2006). The final matrix quantified areas that shifted from deforested to secondary succession and remained in secondary succession throughout the transitions between the 1986–1992, 1992–1996, 1996–1999, and 1999–2003 images. The result is an estimate of the percent of areas in secondary succession that remain in secondary succession by 2003 versus the percent that are re-used and deforested again throughout the 18-year transition (see Table 5). More than half of the area in secondary succession has been re-used within each of the *seringais* by 2003. These numbers suggest a high amount of intensification among rubber tapper households within each *seringal*. The rubber estates in the municipality of Assis Brasil, on average, have lower rates of deforestation, along with lower rates of long-term secondary succession, as well as a higher percentage of areas appearing to capture the swidden/fallow cycle. As a result, Paraguaçu, São Francisco, and Icuriã appear to be areas undergoing less extensification, with greater preservation of primary forests. The *seringais* in Brasiléia, on the other hand, can be classified as areas with generally higher levels of deforestation along with higher rates of secondary succession, apparently emphasizing extensification and other options over more traditional swidden techniques. In Section 4.2,

Table 5. Area and percent remaining in secondary succession and area and percent later reused (swidden/fallow cycle) between 1986 and 2003.

	Porongaba	Filipinas	Humaitá	Paraguaçu	São Francisco	Icuriã
Total area secondary succession between 1986 and 2003 (ha)	428.07	635.45	495.23	378.81	576.63	972.00
Area remaining in secondary succession by 2003 (ha)	175.58	269.92	214.55	57.15	109.27	195.93
Percent remaining in succession by 2003	41.02	42.48	43.32	15.09	18.78	20.16
Percent reused – swidden/fallow cycle by 2003	58.98	57.52	56.69	84.91	81.12	79.84

we use the household data to explain the driving forces of such land change currently underway in the CMER, as well as to explore its relationship to resident well-being.

4.2. Household survey

The results of our household surveys show a wide range of both subsistence and market activities among rubber tappers within the various rubber estates surveyed. The main extractive market activities are the collection of Brazil-nuts and continued rubber tapping for latex production (despite the overall decline of rubber production in the region). Increasingly, small-scale agriculture (beans, rice, manioc, coffee, and corn), animal husbandry (mainly chickens, swine, ducks, sheep, and goats), and cattle ranching are seen by rubber tapper households as necessary income-generating alternatives, given the market instabilities associated with traditional NTFPs. As a result, households are becoming more involved in some sort of market activity beyond traditional extractivism (Table 6).

Multivariate analysis of variance (ANOVA) reveals marked between group differences regarding the percent of households involved in extractivism and agriculture per rubber estate ($p \leq 0.05$) (Table 6). The most dramatic difference is regarding extractive activities. All households surveyed within Brasiléia are involved in some sort of extractivism. The households within the municipality of Assis Brasil are involved to a much lesser extent. Conversely, the majority of households in Assis Brasil are involved in market agriculture,

Table 6. Percent of households involved in market activities in 2003 (n = households).

	Brasiléia			Assis Brasil		
	Porongaba	Filipinas	Humaitá	Paraguaçu	São Francisco	Icuriã
Extractivism*	100.00 (17)	100.00 (26)	100.00 (19)	65.00 (13)	47.37 (9)	10.00 (3)
Agriculture*	58.88 (10)	38.46 (10)	47.37 (9)	90.00 (18)	73.68 (14)	72.41 (21)
Small Animal Production	70.59 (12)	84.62 (22)	73.68 (14)	85.00 (17)	57.89 (11)	68.97 (20)
Cattle	41.18 (7)	53.85 (14)	68.42 (13)	55.00 (11)	52.63 (10)	79.31 (23)

* and ** denote statistical significance at 0.05 and 0.10 levels, respectively (ANOVA test of significance).

compared to less than half of those surveyed in Brasiléia. There are no between group differences regarding the number of households involved in small animal production and cattle ranching for market sale although the extent and intensity varies.

A closer look at the means and standard deviations between *seringais* reveals marked differences and emphases in land-use and land-cover strategies among the households surveyed (Table 7). ANOVA indicates statistically significant between group differences regarding extractive activities between rubber estates ($p \leq 0.05$). There are important differences in Brazil-nut production with the households in Brasiléia producing upwards of 10 times the amount of Brazil-nuts produced in the *seringais* found in Assis Brasil. Brazil-nut prices are consistent and regulated by the larger market, so the distinction in question is not the result of market differences between the two municipalities. Rather, it is the result of ecological differences in terms of forest types between rubber estates. The dense closed canopy forest in the region of Brasiléia is richer in Brazil-nut trees than are the forests of the other *seringais*.

Likewise, the number of rubber trails on each property and the amount of rubber production are significantly different between rubber estates ($p \leq 0.05$). Porongaba and Icuriã (23.59 and 33.93 kg/household, respectively) produce the least latex, while Filipinas and São Francisco produce the most (223.85 and 258.95 kg/household, respectively), thus being the most 'traditional' of the six *seringais* in our study. Note, however, the figures for the two high-latex *seringais* are well below the 1995 reserve-wide average reported as 714 kg of rubber produced per household (Feitosa 1995, p. 72). Although the percent of total income from extractivism remains significantly high, at least in Brasiléia, the percent of the total household income derived from rubber has plummeted from the 44.7% reported by Feitosa (1995, p. 71) to 8.55% in the six rubber estates reported here, making it one of the least important economic activities within our six *seringais*. Not only does rubber production remain highest in our 'traditional' *seringais*, they remain fairly dependent on it, deriving 11.44% of the total household income from the activity in Filipinas and 20.80% in São Francisco. In general, these differences can be attributed to various responses by rubber tappers to the last rubber bust, where some households responded by diversifying their production base, creating new economic opportunities, while others, due to either a strong sense of tradition or insufficient resources or other opportunities, continue to invest in rubber production.

In one instance, however, low levels of rubber production may be attributed to local species abundances and economic inertia. Seringal Icuriã occupies portions of two watersheds and those households located closest to the main community are not rich in rubber trees. Historically, this community served as a hub for the sale of regional latex and, given the proximity to the Iaco River, the transport of latex to urban centers. Many of the residents in this *seringal* did not tap rubber but instead worked in the counting houses, supply good stores, and with transportation logistics regarding the rubber trade. Since both the paving of the BR-317 and changing market conditions, traditional water transport routes for rubber have been either eliminated or have changed, leaving the residents of Icuriã with less of a role to play in the rubber trade and fewer livelihood options, mainly agriculture and cattle ranching.

While the local and regional markets have affected rubber tappers' land-use choices, the density of Brazil-nut and rubber trees appear to do so as well. Pearson's correlation coefficients (Table 8) reveal a significant positive correlation between the percent of total income derived from extractivism and the number of Brazil-nut trees in the *colocação* ($r = 0.467$, $p \leq 0.01$). Similarly, there is a significant positive correlation between the percent of total income derived from extractivism and the number of rubber trails controlled ($r = 0.454$, $p \leq 0.01$). In contrast, there is a significant negative correlation between both the

Table 7. Summary statistics from household surveys: land-use and livelihood statistics (mean and SD).

	Brasiléia			Assis Brasil		
	Porongaba	Filipinas	Humaitá	Paraguaçu	São Francisco	Icuriã
Land holding						
Rubber trails on property (*n*)*	4.29 (2.71)	6.08 (3.32)	4.32 (1.83)	5.60 (3.27)	4.16 (2.27)	1.69 (2.80)
Brazil-nut trees on property (*n*)*	213.00 (245.82)	319.42 (345.31)	358.75 (315.19)	92.25 (91.96)	36.95 (113.94)	2.24 (5.50)
Pasture (ha)**	9.44 (4.13)	7.00 (6.38)	12.03 (12.47)	7.70 (7.95)	7.29 (5.37)	11.72 (7.22)
Swidden agriculture (ha)*	2.94 (2.34)	2.16 (1.49)	1.61 (0.76)	2.25 (1.01)	2.34 (1.83)	3.16 (1.60)
Extractivism						
Brazil-nut (latas)[a],*	318.71 (224.00)	367.54 (375.97)	254.63 (166.92)	22.80 (46.84)	0.00 (0.00)	0.14 (0.52)
Rubber (kg)*	23.59 (75.23)	223.85 (256.55)	125.26 (176.40)	174.00 (349.88)	258.95 (432.14)	33.93 (124.76)
Agricultural production						
Rice (kg)	1030.59 (617.62)	1156.15 (834.40)	738.95 (534.64)	916.00 (647.80)	934.21 (481.33)	916.07 (652.64)
Beans (kg)*	382.94 (344.72)	268.85 (599.58)	228.95 (213.77)	750.00 (580.06)	457.89 (391.67)	395.71 (284.01)
Corn (kg)*	537.94 (546.33)	666.92 (745.57)	557.89 (393.09)	995.00 (945.61)	1121.05 (1258.56)	1239.29 (1010.44)
Manioc flour (kg)*	574.12 (532.81)	599.42 (735.51)	273.63 (418.85)	628.00 (795.18)	331.58 (381.59)	253.93 (195.57)
Coffee (kg)**	20.88 (52.63)	1.00 (4.05)	37.11 (126.00)	173.80 (386.70)	76.00 (320.70)	25.21 (67.92)
Animal production (*n*)						
Chicken	87.35 (136.29)	38.65 (22.29)	39.68 (31.72)	53.10 (27.15)	61.58 (60.09)	63.43 (32.33)
Swine	7.58 (11.04)	9.44 (17.03)	6.16 (9.25)	9.95 (8.25)	12.89 (15.96)	8.64 (9.06)
Ducks	0.94 (2.14)	3.42 (5.81)	1.05 (2.86)	1.10 (2.55)	2.95 (3.92)	3.54 (6.00)
Sheep/goats*	3.00 (4.87)	3.41 (5.23)	7.16 (12.81)	5.55 (9.72)	2.63 (5.59)	9.35 (10.00)
Cattle**	14.18 (13.39)	8.19 (8.31)	19.47 (29.78)	16.55 (20.17)	7.74 (7.36)	17.45 (13.31)
Dependency on activity (% of total income)						
Extractivism (%)*	63.06 (29.10)	74.31 (19.55)	62.84 (24.31)	22.95 (27.96)	20.80 (29.09)	2.95 (11.89)
% of total rubber	0.69	11.44	5.68	10.41	20.80	2.95
Agriculture (%)*	13.60 (17.59)	8.11 (16.00)	7.60 (14.43)	30.64 (30.00)	27.69 (24.23)	35.15 (30.56)
Small animal production (%)*	6.61 (6.89)	9.64 (10.02)	11.26 (14.68)	24.76 (26.13)	11.92 (18.27)	9.38 (12.77)
Cattle (%)*	16.73 (25.70)	7.90 (8.52)	18.46 (22.32)	21.60 (24.29)	18.54 (24.17)	45.30 (31.42)
Livelihood index[b],*	10.71 (3.29)	9.04 (2.63)	11.42 (3.83)	7.90 (3.16)	9.63 (4.57)	11.71 (4.22)

[a]A *lata*, or can, is the traditional system of measuring Brazil-nuts in their brute form for sale (i.e., with shells on). 1 *lata* is equivalent to a 20-L bucket and normally yields about 11 kg of Brazil-nuts.
[b]Based on 30 individual indicators (e.g., overall house construction, appliances, agricultural equipment, access to an electric generator, water pump, safe drinking water, trash and sewage disposal, accessible healthcare, and mode of transportation).
* and ** denote statistical significance at 0.05 and 0.10 levels, respectively (ANOVA test of between group difference).

Table 8. Livelihood index, deforestation, and land-use correlations (n = 130).

	Livelihood index	Agriculture (% income)	Small animals (% income)	Cattle (% income)	NTFPs (% income)	Total deforestation (ha)	Area pasture (ha)	Agricultural plot (ha)	Brazil-nut trees (n)	Rubber trails (n)
Livelihood index	1	–0.047	0.073	0.348*	–0.183**	0.519*	0.491*	0.227*	–0.045	–0.216**
Agriculture (% income)	–0.047	1	–0.079	–0.030	–0.548*	–0.023	–0.060	0.101	–0.252*	–0.225**
Small animals (% income)	0.073	–0.079	1	–0.170	–0.178**	–0.124	–0.149	–0.006	–0.107	–0.003
Cattle (% income)	0.348*	–0.030	–0.170	1	–0.527*	0.384*	0.370*	0.192*	–0.202**	–0.255*
NTFPs (% income)	–0.183**	–0.548*	–0.178**	–0.527*	1	–0.152***	–0.120	–0.218*	0.467**	0.454*
Total deforestation (ha)	0.519*	–0.023	–0.124	0.384*	–0.152	1	0.981*	0.329*	0.080	0.100
Area in pasture (ha)	0.491*	–0.060	–0.149	0.370*	–0.120	0.981*	1	0.235*	0.111	0.120
Agricultural plot (ha)	0.227*	0.101	–0.006	0.192**	–0.218**	0.329*	0.235*	1	–0.184**	–0.068
Total Brazil-nut trees (n)	–0.045	–0.252*	–0.107	–0.202*	0.467*	0.080	0.111	–0.184**	1	0.394*
Rubber trails (n)	–0.216**	–0.225**	–0.003	–0.255*	0.454*	0.100	0.120	–0.068	0.394*	1

*, **, and *** denote that correlation is significant at the 0.01, 0.05, 0.10 levels, respectively.

number of Brazil-nut trees and rubber trails controlled by a household and the percent of total income derived from both cultivation and cattle, suggesting that land users may be choosing livelihood strategies based on ecological constraints due to differences in NTFP potential among forest types.

There are marked differences in agricultural practices among rubber estates that appear to be more subtle than other activities, with different *seringais* emphasizing different products. Outside of manioc flour production, the three rubber estates in Assis Brasil produce greater amounts of beans, corn, and coffee ($p \leq 0.10$) and, other than Porongaba, have among the highest amount of land under agricultural production. Furthermore, the *seringais* in Assis Brasil derive at least twice as much of their income from market agriculture than in Brasiléia. A Pearson's correlation coefficient shows a slight positive relationship between the size of an individual household's agricultural plot and pasture size ($r = 0.235, p \leq 0.01$). Rules that allow a landholder to deforest 2 ha a year (1 ha mature, 1 ha secondary forest) for their agricultural plots may be inadvertently encouraging pasture formation, as it is easier to transform an old agricultural plot into pasture than to go from mature forest to pasture.

In a traditional swidden system, each year a household deforests a small area for agriculture, which in the past would be left to fallow for an average of 3–4 years. Increasingly that fallow is being replaced by pasture and new forest is cut for cultivation. In fact, 56.6% of the households surveyed leave an abandoned agricultural plot to fallow, 13.1% turn that plot immediately to pasture, 19.7% plant *Pueraria phaseoloides*, or tropical kudzu, and 10.6% follow some combination of these options. Tropical kudzu, a legume (nitrogen fixing) and weed-suppressant species, is often planted for forage for cattle and is used in pasture development. The majority of households surveyed in the rubber estates in Assis Brasil leave their abandoned agricultural plots for fallow. The majority of households surveyed in Brasiléia, on the other hand, plant either tropical kudzu or pasture following agriculture, suggesting various land management strategies between the two municipalities.

Pasture and agricultural development have a positive relationship with deforestation, while extractivism a negative one. Interestingly, there appears to be no correlation between either the total area deforested or the total area in pasture, and the number of Brazil-nut trees and rubber trails on household property (see Table 8). These results lead us to believe that the influence on land-use decisions of changing markets and ecological conditions notwithstanding, pushing land holders in one direction or another, decisions regarding the number of cattle to possess and the amount of land to deforest may be based on other social, institutional, or political factors, such as access to capital funds, rubber tapper culture, or participation in the movement. It is important to note that cattle are seen by many rubber tappers as a savings account, an asset to be used in times of distress (Feitosa 1995). This follows a similar rationale among colonist smallholders elsewhere in Acre (Ludewigs 2006) and can be found throughout Amazonia (Faminow 1998; Mertens *et al.* 2002). For other households, cattle are becoming a major market activity (Gomes 2009). Regardless, the investment in cattle pays off as there is a significant positive correlation between the percent of total household income derived from cattle and the livelihood index ($r = 0.384$, $p \leq 0.01$), while there is a negative correlation between the percent of total income derived from extractivism and the quality of life (livelihood index) ($r = -0.183$, $p \leq 0.05$). Agriculture and small animal production appears to have no significant relationship to livelihood, but a significant positive relationship exists between deforestation and a household's livelihood index ($r = 0.519, p \leq 0.01$).

Overall the *seringal*-level household results suggest that Seringal Filipinas and São Francisco are the most 'traditional' rubber estates with the highest latex production and lowest amounts of both cattle (8.19 and 7.74 ha) and pasture (7.00 and 7.29 ha) per household. Households in Humaitá have the greatest amounts of both pasture (12.03 ha) and cattle (19.47 ha) but also remain involved to some extent in a variety of extractive activities. Icuriã has the second highest reported amounts of both pasture (11.72 ha) and cattle (17.45 ha). While Humaitá and Icuriã appear to be the least 'traditional' of the rubber estates, the communities of Porongaba and Paraguaçu reside somewhere in between these two nodes in terms of both pasture (9.44 and 7.70 ha) and cattle (14.18 and 16.55 ha). With the exception of Icuriã, these results are consistent in explaining the deforestation trends outlined previously in the remote sensing analysis.

5. Discussion

The results suggest that the label 'rubber tappers' for the occupants of the CMER may be a misnomer. In fact, among the *seringais* surveyed here, households pursue diverse livelihood practices including extractivism, small-scale market cultivation, small animal rearing, and, increasingly, cattle production. Rubber tapping plays an increasingly less important role in livelihood strategies. Still, the majority of households surveyed identify themselves, for historical, cultural, and political reasons, as rubber tappers first and foremost, rather than colonists, small-scale ranchers, or agriculturalists. Indeed, some evidence suggests that rubber tappers' involvement in agriculture and small-scale cattle rearing is not just a recent development, but always existed, although to a much lesser extent, since the rubber barons abandoned their rubber estates in the 1960s and 1970s (Murrieta and Rueda 1995; Gomes 2004). The main change is not the adoption of such activities; it is the extent of their use and relative proportion of household income. Rubber tappers are no doubt being influenced by development forces operating outside the CMER. In Acre, rubber has descended from the most important economic activity to one of the least, while cattle and cultivation have become increasingly important. Thus cattle have a ready market outside of the reserve, while many rubber and extractive products simply do not. Understanding the land dynamics in the reserve requires the expansive interpretation of the rubber-tapper label that is held by the occupants and central to their land-use decisions.

According to the remote sensing analysis, none of the six *seringais* surveyed here have surpassed the 10% limit set on the amount of allowable deforestation by 2003, although at least one trend projection indicated that this limit would be exceeded by that date. Humaitá and Porongaba are, however, close to reaching this limit. It is also noteworthy that some *seringais* may have passed the 5% allowable for pasture (roughly 15 ha per household).[3] Compared to other land users in Amazonia, deforestation rates remain low, however. Evidence of high amounts of land in secondary succession in Brasiléia and increasing intensification among land users in Assis Brasil suggests that rubber tappers may be undergoing a process of adaptation that may alleviate deforestation pressures with proper management. The reserve provides other important environmental services that must also be considered. The CMER currently serves as a firewall, buffering the rain forest (located between highly deforested cattle ranches and largely forested indigenous communities) and offering biodiversity protection (Brown 2004; Vadjunec 2007).

Pastures for cattle and crop development are the greatest drivers of deforestation within our study areas and appear to be negatively correlated with extractive activities. The rubber estates with the highest amount of cattle also have the highest amount of deforestation. The only exception to this trend was Seringal Icuriã, but this may be due to inconsistencies with both population dynamics and boundary issues. Cropping plays more of an important role in the rubber estates of Assis Brasil where natural forest differences resulting from the division of the watershed limit NTFP extractive potential. Furthermore, cultivation is linked to deforestation because increasingly households convert their abandoned agricultural plots to pasture instead of leaving them to fallow.

As expected, Filipinas and São Francisco, the two most traditional extractive *seringais* (in terms of sustained emphasis on latex production), had fewer cattle, maintaining among the lowest rates of deforestation. This result suggests that investments in non-timber forest projects might be beneficial to forests. As currently practiced, however, emphasis on NTFP production does not appear to better livelihood conditions. For extractivism to be a serious contender, these traditional *seringais* press for the return of long-term and realistic subsidies, supporting rubber collection as well as heavy investments in other 'green' products such as *açai* fruit, honey, vegetal leather products, and handicrafts. The pro-forest government of Acre has already started to invest in these areas, with the creation of a condom factory in Xapuri, for example, but it remains to be seen whether it will get residents back to rubber tapping, let alone working in other NTFP activities.

Most of the debate surrounding cattle in the CMER focuses on deforestation for pasture, but such arguments need to be expanded to include considerations of both secondary regrowth and the swidden/fallow cycle. The remote sensing analysis shows that much of the deforestation in the six *seringais* surveyed here is permitted to move into secondary succession, and over half of the area in secondary succession is re-used at a later time period. Thus a significant proportion of the disturbed land cover in the study area remains in some disturbed condition and is not permitted to reach mature stages of forest regrowth. Rubber tapper households appear to be changing their production systems. Although most rubber tapper households are not expanding their agricultural plots per se, they may be using the '2-ha per year' rule to augment their pasture size on a yearly basis. Overall, the results suggest that land-use and land-cover change, and even the responses to such change, is dynamic in the CMER. Aside from changing market and land-use emphases and the resulting variable rates of deforestation, there are also increasing differences in production systems and technologies adopted by rubber tappers as their main source of livelihood begin to change, suggesting not only extensification but also intensification.

Lastly, it is obvious from this exercise that new property boundaries of some *seringais* are needed. Icuriã is a case in point, a community in which the official digital rubber estate boundaries appear to be inconsistent with both the community's and the local officials' definition of the actual *seringal*, with some officially recognized residents appearing to live outside of both the reserve itself, as well as the community. In addition, various boundaries exist for a few of the *seringais* in the CMER that have size differences of as much as 15%. Such variances no doubt affect the results of the deforestation amounts and rates reported here at the *seringal* level. When the question of which boundary to use arose, we opted for the boundaries that most incorporated the households surveyed within the specific community, relying on both GPS points and field experience in the region. If remote sensing is to be considered a serious tool for monitoring the sustainability of the CMER, it is crucial that these issues be resolved.

The discrepancy with Icuriã between the high amount of land reported by households to be in pasture and the low levels of actual deforestation found in the remote sensing analysis points to yet another issue; mainly, extenuating ecological circumstances caused by the division of the watershed, making much of the *seringal* uninhabitable. Unlike the five other rubber estates in this study, where all land is claimed by some household or another, much of Icuriã is without water (or Brazil-nut trees) and consequently without households. These vast tracks of barren land create an unfair advantage for the residents of Icuriã when monitoring the 10% rule at the community level. Exceptions like Icuriã reveal the limits to a remote sensing approach when monitoring the adherence of households to the rules outlined in the

UP and show why it is important to monitor the reserve's efficacy on the ground. Given these new boundary issues in an historically common property system where property is defined by access to trees and trails, rather than geometric space per se, we argue that in order for monitoring to be effective with the adoption of new land-use practices, authorities really need to invest in mapping properties at the household (*colocação*) level. This will ensure that effective and timely monitoring can, indeed, take place.

6. Conclusions

The search for a 'win–win' scenario in the CMER and other extractive reserves in Brazil appears to be far more complicated than the simplified notion that rubber tapping and other NTFP activities can provide improved material for well-being while preserving tropical forest. Indeed, many rubber tappers face production constraints by ecological conditions beyond their control. Furthermore, the majority of rubber tappers themselves, at least in this study and most likely for the CMER, define their 'rubber-tapper' label as including a wide-range of activities that require the forest to be cut, perhaps increasingly so. Overall, when compared to outside colonization projects and ranching operations, the deforestation occurring within the CMER can be considered quite low, but when looked at as a conservation unit, the six *seringais* examined are undergoing surprisingly rapid land-use and land-cover changes with cattle and agriculture as the main drivers of such change. Such changes are inextricably linked to current outside market influences, which privilege cattle to NTFP extractivism. As of 2003, however, none of these six *seringais* had surpassed the 10% limit set on the amount of allowable deforestation. While some communities may surpass allowable deforestation limits in the near future, evidence of intensification among land users suggests that rubber tappers may be undergoing a process of adaptation that alleviates deforestation pressures while providing improved incomes. After all Holt (2005, p. 209) argues that 'conservation develops as a result of experience and learning, sparked by negative changes in resource characteristics'. The environmental changes now underway may be capturing this learning and adjustment process, rather than a long-term trend suggesting system unsustainability.

Much of the current criticism questioning the sustainability of the CMER, and the entire RESEX model, may reflect biases or misconceptions regarding the character of 'rubber tapping' livelihoods as well as the 'pristineness' of Amazonian forests. The murder of Chico Mendes has been enlarged to equate cattle with 'evil' livelihoods. As a result of such caricaturizing, the mere idea that the rubber tappers championed by Mendes are now raising cattle themselves is met with little enthusiasm by some proponents of the extractive reserve concept. It must be remembered that Chico Mendes and the rubber tappers may have been fighting for the forest, but also, and more importantly, for a right to both a better livelihood and land security.

Cattle and market agriculture are and will likely remain part of a rubber tapper's land-use system and consequently need to be addressed realistically in terms of appropriate policy development for the rubber-tapper populations in the region. Rubber tappers want technical support regarding agricultural development, particularly pasture formation and its sustained use. Cattle, however, remains a 'dirty' word in the CMER, and rubber tappers continue to find little support, information, or new policy and regulations regarding such matters. The results of this study show that cattle are positively linked to both livelihood welfare and deforestation, while dependence on extractivism (at least as currently practiced) is linked to a decrease in welfare, as well as a decrease in deforestation. Our suggestion, therefore, is two-fold. Policy directions for both the CMER and the RESEX model need to focus on cattle regulation and sustainable pasture management, as well as a serious re-investment in NTFP marketing and development in order to make extractivism more viable.

Notes

1. Increasingly, the concept of extractive reserves is expanding, being applied to a diverse range of ecological and social contexts outside of Amazonia, including non-rainforest environments, such as marine areas on the Atlantic coast of Brazil, and increasingly in savanna ecosystems where soybean expansion threatens both local environments and traditional populations (Thuelen 2006).
2. While we recognize that state-run extractive reserves in Rondônia are currently undergoing extreme land-use pressures (Euler *et al*. 2008), we argue that they should be considered an exception, not the norm, and addressed separately from the RESEX system.
3. Due to the common property aspects of the reserve, the difficulty mapping at the household level, and the fact that many households actually create pasture together, while other households rent their pasture out, we rely on the remote sensing results to test the efficacy of the deforestation rules and use the household-level data to explore relationships between land-use, deforestation, and well-being.

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