REFORESTATION AMIDST DEFORESTATION IN THE BAYANO-DARIÉN FRONTIER, EASTERN PANAMA: VARIATIONS ON THE FOREST TRANSITION THESIS

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ABSTRACT

The literature on tropical forest-cover change observes a set of drivers responsible for transitions toward reforestation – the so-called 'forest transition'. Uncertainty still exists over how the drivers behave in the transition and how trends in reforestation manifest in different contexts. Focusing on the Panamanian agricultural frontier of the Bayano-Darién, this thesis combines household surveys, remote sensing / GIS analysis and participant observation to describe nascent trends in reforestation for key actors and scales, and in relation to antecedent patterns pattern of land-cover change. Results indicate that the forest-transition is aligned with the patterns of previous land-cover change. In Eastern Panama, reforestation appears as a fringe event in the landscape. Though reforestation is popular with some large-scale actors, smallholders continue to convert forest to pasture, resulting in net deforestation.

RESUME

La littérature concernant le changement de couvert forestier tropical observe qu'il y a une série de facteurs de changements occasionnant un phénomène de reforestation, dénommé la 'transition forestière'. Des incertitudes persistent quand aux comportements de ces facteurs de changements dans ces transitions forestières, ainsi que relatives à la manière dont se manifestent différentes tendances dans différents contextes. Cette thèse se focalise sur la frontière agricole dans la région de Bayano-Darien au Panama. Elle allie des enquêtes ménages, l'analyse d'images satellitaires/systèmes d'information géographique (SIG) et l'observation directe afin de décrire des tendances émergentes de reforestation chez des acteurs et à des échelles clés et mettre en relation des changements précédents d'occupation du sol. Les résultats indiquent que la transition forestière est liée avec des utilisations passées du territoire. Dans l'est du Panama, la reforestation apparaît comme un phénomène marginal dans le paysage. Malgré le fait que la reforestation soit populaire avec certains grands acteurs, les petits propriétaires terriens continuent a convertir forets en pâturages, ce qui résulte en une déforestation nette.

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INTRODUCTION

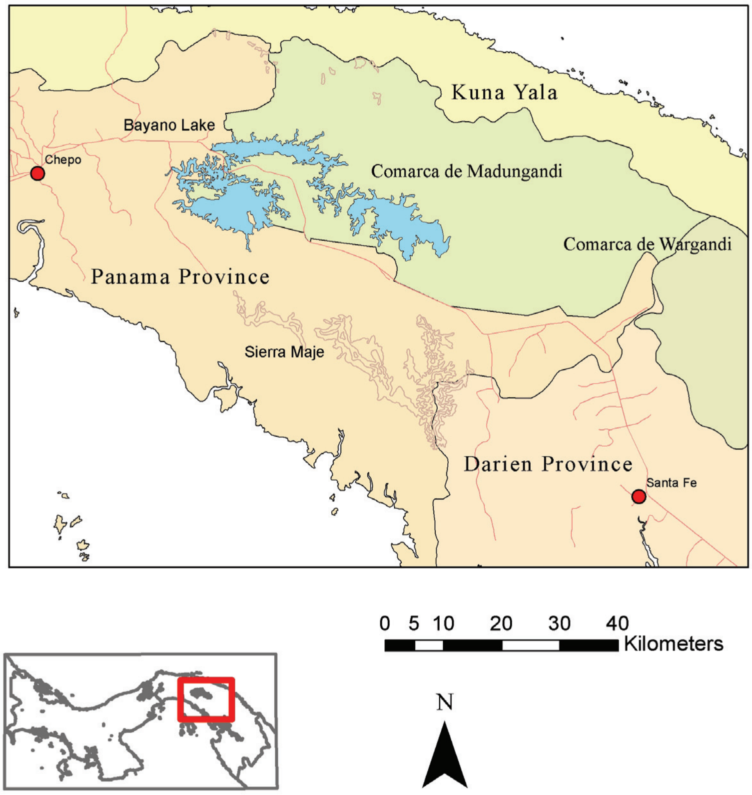
Tropical deforestation represents one the greatest threats to the integrity of our biosphere, the stability of our climate, the abundance of our natural resource base and our legacy for future generations. Still, forests continue to fall at a rapid pace. Since the 1990s, however, geographers of tropical land-use and land-cover change have increasingly observed reforestation events that partially restore landscapes and counter, if not overtake, long-established trends in deforestation. These events, called forest transitions, appear to loosely conform to a pattern observed in Western countries over the last 200 years, though with notable exceptions. Unlike Western countries of the 18th and 19th Centuries, modern tropical nations must deal with an entirely new global economy, a larger and more marginalized population, and patterns of land-use/cover change specific to tropical contexts. As such, trends towards reforestation presently observed in some tropical regions and countries should display important deviations and be subject to distinct forces relative to the Western model of forest recovery.

Only during the last few years has research sought to highlight the distinctiveness of a tropical forest transition. This research has focused particularly on determining the correlates of forest recovery in tropical countries and on describing the combinations of these correlates and conditions that best facilitate reforestation. This scholarship now seeks to define numerous pathways of reforestation, which complement the well-known and various pathways of deforestation. Similarly, this research has highlighted the fact the global tropics is a very large and diverse arena of forest-cover change, within which reforestation is more or less likely depending on circumstances particular not to countries but to regions within countries. The tropical forest frontier, the setting for this thesis, is one such region common throughout Latin America and facing widespread and persistent deforestation. Within the frontier, a characteristic and long-established pattern of land-use/cover change has converted forest to pasture and other extensive land uses. Though persistent, this pattern of land use may adopt new forms reflective of the ongoing urbanization and globalization in tropical countries. Importantly, this pattern of land use parallels the forest transition in some respects, and in taking new forms in the 21st Century may provide opportunities for reforestation. This thesis seeks to better explicate the forest transition with reference to its nascent ascent in a forest frontier in eastern Panama and its simultaneity with and succession of predominate land-use dynamics.

The Bayano-Darién agricultural frontier incorporates the area from Lake Bayano to the town of Sante Fe, Darién, and from the Sierra Majé to the forested indigenous reserves of Comarca de Madungandi and Comarca de Wargandi (Figure 1). As recently as the 1960s, contiguous tropical forest stretched from Chepo town in the far west of the Greater Bayano Region to the Colombian border in the east. Since the early 1970s, *mestizo* agriculturalists from Panama's interior have colonized the frontier and converted much of its forest cover to pasture and subsistence agricultural plots. Over the 1990s, emigration characterized many villages and corners of the frontier, while simultaneously the Panamanian government provided landholders with reforestation incentives. Together, emigration and reforestation incentives created opportunities for reforestation, which coincided with persistent rationales amongst *mestizos* to convert forest to pasture.

Fieldwork in the Bayano-Darién took place from May through October of 2006. Four stages mark this thesis' methods and analysis. In stage one, Landsat satellite images of the Greater Bayano Region and of Los Santos province of Panama's interior were processed to quantify forest-cover change for each area over the period 1970 to 2000. In stage two, a survey of 55 colonist households in the Bayano-Darién frontier gathered data on household land-use/cover and socio-economic change since the 1980s. Household histories of land-use/cover change since 2000 were regressed on socio-economic variables to quantify proximate determinants of reforestation, deforestation and pasture expansion. In stage three, an on-farm survey and aerial-photo analysis yielded geo-referenced land-use/cover data for 3016 ha of different land covers. These data were used to convert Landsat satellite imagery of the Bayno-Darién frontier for the year 2000 into a land-use/cover map that was, in turn, compared with a similarly produced land-use/cover map for 1990 to assess land-use/cover change over the 1990s. Finally, a database of 1568 cases of plantation afforestation nationwide and 94 cases for the Bayano-Darién, representing all plantations subsidized by government, was analyzed to determine who afforests, how much do they afforest, where they do so and when.

Figure 1 – The Bayano-Darién Region, Eastern Panama.



Source: Author. Spatial data provided by Contraloría General de la República de Panamá

This thesis represents a collection of discrete manuscripts that discuss different aspects land-use/cover change in Panama, with particular focus on transitional trends in reforestation. Chapter 1 reviews evidence for different theories of land-cover change in the tropics, including the forest transition, and considers the potential for simultaneity or succession between them. Chapter 2 challenges a recently published account of global tropical reforestation due to rural depopulation. With reference to the Bayano-Darién and other Latin American forest frontiers, Chapter 2 demonstrates that urbanization and rural depopulation alone are insufficient to ensure reforestation, and argues that future analyses should focus on regional dynamics of land-use/cover change. Chapter 3 presents a data-intensive account of forest-cover change at the household and landscape scale in the Bayano-Darién since 1990. It highlights the parallels between the observed-pattern of reforestation and antecedent pattern of forest-to-pasture conversion, which optimistically suggest that a forest transition may indeed follow even a well-established pattern of deforestation if key contextual features are 'shifted' favourably. The chapter also demonstrates, however, that smallholding peasants do not adopt reforestation but continue to counteract it converting forest to pasture.

The thesis concludes by summarizing the findings of each chapter. Above all else, this study observes that, in conditions of forest abundance, and barring a large-scale depopulation of the rural landscape, reforestation is likely to remain a relatively unimportant event and the realm of large-scale commercial interests. Smallholders, in contrast, are likely to resist incentives to restore or conserve forest cover and to continue to depend on the conversion of tropical forest as a critical element of their livelihood.

CHAPTER 1

A REVIEW OF FOUR THESES OF LAND-USE AND LAND-COVER CHANGE IN TROPICAL COLONIZATION FRONTS: IS THERE POTENTIAL FOR SIMULTANEITY?

Sean Sloan

1.0 Introduction

In light of the general relationship between proximate and underlying causes of land-use and land-cover change (LUCC) (Geist and Lambin, 2002; Lambin et al., 2003; Lambin et al., 2001) I examine in this chapter four theses of LUCC in tropical contexts that integrate either proximate and/or underlying drivers to varying degrees. These theses are: the household life-cycle thesis, the Boserupian thesis, the hollow-frontier thesis and the forest-transition thesis. These theses approximate a spectrum of proximate-to-underlying explanation of LUCC. In examining these four theses this paper asks 'how does each explains LUCC in tropical forest frontiers'? In answering this, I am also able to answer another question: 'how do the theses' explanations of LUCC converge with and diverge from each other'?

As expected, no thesis is sufficient on its own. Indeed, the most proximate thesis (life-cycle) is confounded by underlying forces, and the most underlying thesis (forest-transition) is weak and vague without reference more localized cases. The theses also tend to converge with each other, but only to a point, after which they offer divergent accounts of LUCC that disparities between theses' scales of analysis do not explain. Divergent accounts do not imply flaws in any of the theses. Rather, each validly describes slightly different scenarios on a spectrum of LUCC possibilities. I conclude with two implications, the first being that LUCC on a tropical colonization frontier is a dynamic process in which the mechanisms described by seemingly distinct theses operate concurrently and, as a corollary, that multiple theoretical frameworks should be simultaneously employed to describe LUCC.

2.0 The Household Life-Cycle Thesis

Lambin et al. (2003) assert that LUCC is ultimately due to underlying long-term macro-scale processes. Yet, in the span of a generation, Lambin et al. (2001) also assert that most land-use and land-cover change occurs at the proximate scale. The household life-cycle thesis (LCT) of land-use and land-cover change agrees in illustrating that, at the household scale and over a single generation, significant LUCC results from proximate forces largely independent of macro-level forces external to the context in question. This section describes the LCT, offers evidence in support of the thesis and discusses its shortcomings.

2.1 Summary of the Life-Cycle Thesis

The LCT is based on Chayanov's (1966 [1925]) observations made in an early Russia when land abundant, not unlike modern tropical agricultural frontiers. Chayanov explains differences in Russian peasant households farm sizes and associated farm systems and surpluses as a function of household dependency ratios, defined as the ratio of a household's consumers to its adult workers. The LCT extends this premise to contend that households experience changing needs, objectives and capabilities over their life course as their dependency ratio oscillate, and that peasants' land uses reflect this oscillation.

The LCT for tropical agricultural frontiers is summarized as follows: To begin, a young household migrates to the extensive margin of agriculture (i.e., the frontier). By virtue of being a young household, familial labour resources are few, the dependency ratio is high and risk aversion relatively pronounced (Walker et al., 2002). The young household thus concentrates its resources on the production of annual crops (e.g., rice) in efforts to sustain itself with minimal risk. Notably, owing to risk aversion and labour constraints, the young household does not invest in future production but rather concentrates on short-term production of annual crops for immediate consumption

(Walker et al., 2002). In subsequent household life-cycle stages, the household's children increase in number and age, and thus place a greater consumption demand on household production. Concurrently, the older children add their labour power to the household's total labour pool, alleviating and eventually reversing the consumptive strain. Household risk aversion and discount rates then subside, farm expansion and diversification occur, and farm systems based on perennial plantations and cattle are adopted as the household invests in more remunerable land uses for the long term. Ultimately, in the final life-cycle stage, the household's children mature and form their own households, raising the dependency ratio and leading the farm enterprise to contract and resemble that of a young household. No indication is given as to how an older family manages the physical demands of agriculture, but presumably the older household retains some of the fruits of earlier investments such as pasture in order to retain productivity.

2.2 Evidence for the Life-cycle Thesis

To the extent that life-cycle stages influence LUCC, frontier populations of similar wealth and age should exhibit synchronized, regional-scale transitions in farming systems and forest-cover change. Walker and Homma's (1996) observations for colonists in Pará, Brazil appear to confirm this expectation. In the 1970s recently-settled colonists concentrated production on annuals (namely rice), held little land and pasture and featured modest agricultural diversity. Fifteen years later – roughly the time needed for children to mature – land in annuals increased by one hectare per household on average, presumably to feed additional family members, while land in investment actives increased markedly; perennial plantations were observed more frequently, land in pasture increased six-fold (6.3 ha to 37 ha) and herd size increased twenty-five-fold (1.4 head to 35 head). Walker and Homma (1996) explain such changes via the life-cycle thesis, as observed in Bolivia (Stearman, 1983) and Colombia (Ortiz, 1984); yet as Walker and Homma (1996) neglected to track individual households or employ statistical analysis, but instead relied on descriptive statistics from two separate surveys, they could not substantiate their claims.

Walker et al. (2002) later tested LCT explanatory variables again in Pará, Brazil, and bore generally affirmative yet somewhat ambiguous results. In support of the LCT, they observe that 'low-value farm systems' (i.e., annuals-orientated) are associated with higher dependency ratios and less familial labour than 'higher-value farm systems' (i.e., predominantly perennials or pasture). Also, households' duration of residence in the frontier and dependency ratio significantly predicted farm diversity and, by extension, 'mid-value farm systems' such as annual-perennial combinations. However, like other studies relating life-cycle stage to farm-system choice (Alston et al., 1993; Alston et al., 1996) the results suggest weak or inconsistent relationships, affected by exogenous factors such as proximity to roads (Walker et al., 2002). In turn, these weak relationships suggest that though life-cycle stages can account for land allocation to annuals, perennial, pasture or forest (e.g., Pichón, 1997) their relevance to farm-system choice is more easily confounded.

A more promising application of LCT has been in the coarser analysis of forest-cover change (McCracken et al., 1999a; McCracken et al., 1999b; Moran et al., 1996; Perez and Walker, 2002; Walker, 1999). McCracken et al. (1999a) crossed household survey data with land-cover data at the farm-property level over twenty-one years and observed statistically significant interactions between life-cycle stages and forest-cover change. Households in advanced life-cycle stages held properties far less forested but with more forest regrowth (per annum and total area) than households in earlier life-cycle stages, who in contrast exhibited high annual deforestation rates and strong negative correlations with forest regrowth. Properties with greater proportions of previously forested land in pasture - an assumed indicator of later life-cycle stages - had little remaining forested area but also a minimizing effect on annual area deforested in the three years preceding the survey. Properties with greater proportions of previously forested land in annual field crops - an assumed indicator of earlier life-cycle stages - had similarly negative effects on standing forest area[1] but with a much stronger, positive correlation with annual deforestation rates in the preceding three years. The authors explain the differing rates and directions of forest-cover change with reference to the disparate farming systems adopted by households in various life-cycle stages. These findings are supported by Perez and Walker (2002) and Walker (1999).

2.3 Shortcomings of the Life-cycle Theory in the Context of Colonization Fronts

The shortcomings of the LCT as applied to a modern tropical frontier owe primarily to its Chayanovian foundations. Shortcomings pertaining to dynamic household consumption, frontier livelihood strategies, and an a-contextuality of the thesis are summarized below.

[1] This statement made on the basis of the regression coefficients for pasture and field crops, each explaining variation in total forested area remaining at the time of the survey.

Chayanovian theory assumes household per capita consumption is fixed. As household needs are met, household production should therefore plateau, thereby maintaining a production-consumption equilibrium (Chayanov, 1966: 41). This conception of peasant economics is valid perhaps only for the closed peasant communities described by Wolf (1957). It is doubtful that, as a children mature and assume greater responsibility, the labour investment of adult household members will drop to maintain constant production and consumption levels while, nearby, better-off neighbours enjoying the fruits of their labours doubtlessly provide motivation for greater accumulation (Barlett, 1980: 143). Fixity of consumption becomes tautological as the definition of household needs expands to include arguably modern necessities such as batteries, fertilizer or bread. Contrary to the fixity of consumption assumption, peasants, like all social actors, have strong consumptive aspirations that grow in proportion with income and productive capacity (Barlett, 1982: 149-59).

Due to the fact that life-cycle factors such as family size, number of children and deforestation all naturally increase with time, and thus with life-cycle stages as well, it is possible that correlation / regression coefficients overstate their covariance. The apparent unimportance of household age is illustrative. A survey of quantitative LCT studies suggests that the age of household head is often weakly and inconsistently related to expected LUCC outcomes (Walker et al., 2002). Also, reviews of tropical resettlement programs suggest that insecurity, and not household age per se, explains household agricultural change over time in frontiers (Kinsey and Binswanger, 1993; Scudder, 1985). Scudder (1985) details that household security is foremost in settlers' agendas, not because new settlers are young and so (supposedly) risk adverse, but because colonization is initially a risky endeavour. The recently settled therefore naturally adopt conservative and consumptive postures (e.g., wholly subsistence short-term cultivation) to attain and protect security, and only upon the attainment of security do they transition into more dynamic and investment-orientated activities (Scudder, 1985). Notably, this conservatism applies regardless of life-cycle stage. Further, this transition period lasts one-to-two-to five-to-ten years (for sponsored settlements) (Scudder, 1985), the same time frame the LCT suggests is needed for young families to transition from subsistence crops to investment crops (McCracken et al., 1999b). This suggests that LCT's formulation is overly theoretical and lacking contextuality; it is true, after all, that young families are over represented in colonization frontiers. Though Walker et al. (2002: 178) assert that the "duration of residence amounts to an incomplete specification of the 'location' of a household along the life cycle" it would seem that duration of residence matters more to LUCC than household age.

The frequent division of a household's lifespan into an arbitrary yet undefined number of stages also constitutes a weakness. Household behaviour may be observed within and explained by a particular life-cycle stage relative to another, but only until the categories and number of stages are redefined such that new behaviours are observed within the new stages. The problem thus resembles the Modifiable Areal Unit Problem (Burt and Barber, 1996: 109, 403), whereby different spatial patterns are observable upon reconfiguring the boundaries of aerial units (e.g., census districts) within a single area (e.g., a city), and tautological explanations are again common. Walker et al. (2002), for instance, observe two life-cycle stages ('early' and 'late') and concludes young households are unwilling / unable to make longer-term investments by virtue of adopting cattle at a 'later' life-cycle stage. Conversely, McCracken et al. (1999a) conceptualize five life-cycle stages and conclude that cattle are incorporated relatively earlier as a means of increasing longer-term wealth with a minimal labour allocation.

Although the Chayanovian context approximates that of Latin American tropical frontiers in terms of land abundance and limited agricultural technology, it does so less well upon considering the livelihood strategies of the peasants colonizing such frontiers. As colonizers penetrate the frontier, the untitled and unregulated nature of the land may encourage colonizers to acquire more land that actually ‘required’ to meet immediate consumption needs (Gudeman, 1978; Imbernon, 1999). Indeed, the nature of land and land titling in a tropical forest frontier means households may (a) seek to freely acquire as much land as they can early on (Mertens et al., 2002; Moran, 1981), for use and for speculation, (b) cannot intensively cultivate a plot of land for more than three seasons, and (c) therefore maintain claim to their cultivated and depleted lands by placing them into active extensive uses, namely cattle (Heckadon Moreno, 1981; Williams, 1986). In practice, this means colonizers tend to clear forest and progressively convert land from annuals into pasture as a matter of context and not life-cycle stage.

In summary, the LCT elucidates land-use dynamics unobservable at larger scales of observation. The thesis attempts to explain not only allocations of acreage to competing land uses but also the adoption of entire farming systems and associated land-cover change. Notwithstanding its accurate predictions of forest-cover change, consistent predictions of expected land-use outcomes depend greatly on restrictive provisos. In practice, exogenous factors may confound the LCT's explanation of farm-system adoption. The LCT may therefore be efficacious only as a 'background theory', that is, a theory able to explain LUCC with reference to endogenous, natural phenomena in conditions of autarky but which is easily over-ridden by forces less 'natural' to the context, namely spatial and market forces.

3.0 The Boserupian Thesis

Boserupian theory (Boserup, 1965; 1981) depicts LUCC induced by peasants' adaptations to the simultaneously endogenous and exogenous conditions of land scarcity. Boserupian theory may approximate the LCT in its spatial scale but is distinguished by its greater temporal scale. Whereas the LCT considers household consumer-to-producer ratios and envisages household labour as a cyclic and oscillating influence on LUCC, Boserupian theory often considers land-to-population ratios at a more regional geographic scale and envisages population as a cumulative factor influencing the evolution of farm systems, land-tenure and associated LUCC. The following describes the Boserupian thesis, presents supporting evidence and discusses it shortcomings in the context of colonization frontiers.

3.1 Summary of Boserupian Thesis

The Boserupian thesis of LUCC can be summarized thusly – where a 'primitive' agricultural population places increasing demands on the land's productivity, typically through increased population pressure and/or by undermining soil fertility, the predominant and increasingly insufficient farm system(s) as well as the underlying land-tenure system(s) are modified in a predictable, step-like evolution toward intensification. Five successive stages of agricultural organization characterize this evolution (Boserup, 1965): (1) forest fallows of 20-25 years, (2) bush fallows of six-to-ten years, (3) short fallows of one-to-three years, (4) sedentary annual cropping, and (5) sedentary multiple cropping (more than one crop per year per plot).

The succession of stages typically proceeds in only one direction, from less to more intensive cropping. Contrary to the use of the term ‘evolution’, however, the progression of stages may often be detrimental to local cultivators. To elaborate: upon increasing demands on the land, a population will alleviate pressure by spatially expanding its insufficient tenure system (e.g., stages one and two) to incorporate unused or under used and typically marginal lands. Should the agricultural yields inherent to the tenure system remain inadequate relative to the population's consumption demands, the land usage inherent to the tenure system is applied more intensively, though it is not yet modified - for instance, fallow periods are shortened yet rotations and agricltural technology remain unchanged (e.g., stages two and three). This intensification without mod ification proves unsustainable. Soil fertility is depleted, and farm yields and labour efficiencies decline steeply, thus exacerbating the original pressures on the land. Prolonged pressure of this kind induces experimentation and innovation until an agro-technological solution to the production-demand imbalance is found, as in the form of new rotations, improved crops varieties, new fertilizing methods or new forms of land ownership. The initial tenure system is then modified and replaced with a version that is better able to allow farmers to meet consumption demands (stags four and five). As the initial tenure system successively 'evolves' into more intensive versions over the depleted soils, more food is produced in absolute terms and the population pressure subsides. At graduated stage of evolution, however, the workload necessary for a unit of production is much greater, as agricultural labour efficiencies decline in parallel. Further, where fertile soils still remain such that earlier tenure systems are still viable, markedly superior labour efficiencies and even absolute yields are still possible. Thus, Neil (1984) considers the intensification and 'evolution' of agricultural systems as wholly undesirable from the producer's point of view and undertaken only when extensive tenure systems are thoroughly prohibited by a depleted resource base or heightened demand for land. Therefore, one might anticipate observing the predominance of more primitive agricultural systems wherever they are still viable, as amongst Amerindians of the Amazon (Dufor, 1990). To the extent that this is not observed, as in qualifications to the assumptions underlying the Boserupian thesis are in order.

3.2 Evidence for the Boserupian Thesis

Unlike the LCT, Bosuperian theory considers exogenous, society-wide factors relative to a single household's potential land-uses. In an old Costa Rican frontier Barlett (1977; 1982) observes how campesinos' land-use decisions are based partly on the availability of young male household labourer (an endogenous factor) and partly on the amount land available to a household (an quasi-exogenous factor conditioned by endogenous factors, such as societal inequality and commodity prices for beef). In stratifying households by their access to land rather than by labour or life-cycle stage, Barlett (1977; 1982) illustrates not only the unique livelihood strategies of each household stratum relative to the size of their landholding but also a clear tendency for even the poorest and most land-deprived households to undertake economically dynamic, intensive agriculture for household investment. Indeed, in Barlett's study, it is a household's ability to continually apply at least one male labourer to intensive investment crops and reinvest profits into the purchase of land - and not laboural capacity to clear land and raise perennials - that determines household farm size. Correspondingly, it is farm size that largely determines what land-use strategies a household adopts. For example, small holders select land and labour-intensive tobacco production to maximize profits per unit land while achieving low labour efficiencies, while large holders select land-extensive cattle production for absolute profit maximization with high labour efficiencies yet low revenues per unit land. While a minimal presence of male household labour is essential to a household's upward mobility, it is a household's respective land endowments – and not household age or labour capacity – that lead to different land-use strategies. Consequently, as land endowments change upon growing Boserupian pressure, so do the uses to which they are put. The primacy of farm size relative to labour resources as determinants LUCC may have less importance in newly settled land-abundant frontiers relative to long-settled and more land-scarce areas. Further, though Boserupian theory takes note of forest-cover change, it does so indirectly via its focus on land use and fallow periods. *Rates* of forest-cover change as predicted by the LCT may therefore hold true even within a LUCC dynamic characterized as Boserupian, except perhaps in contexts of acute land scarcity.

3.3 Shortcomings of the Boserupian Thesis in the Context of Colonization Fronts

Barlett's (1977; 1982) case study of Paso, Costa Rica exhibits clear outcomes of Boserupian 'evolution'. There, landowners adopted reduced average plot sizes, shortened fallows and adopted increasingly sedentary agricultural practices and intensive multi-cropping despite lesser labour efficiencies. Nonetheless, on smaller plots the intensified farm-system characterized by the sedentary multicroppping of tobacco, corn and beans is, in fact, remarkably similar to the traditional farm system characterized by shifting cultivation of corn and beans. The intensified farm system is differentiated from the traditional system primarily by (1) being sedentary for lack of fallow lands, (2) its heavy use of chemical fertilizer and soil treatments made possible by (3) access to credit for growing tobacco in tight rotations with corn and beans, which virtually anyone could acquire and thus (4) its relatively greater risk to growers (Barlett, 1982: 78-88). Whether this new system is a Boserupian 'evolution' under pressure or merely the traditional system propped up by cheap credit and chemical fertilizers is the question. The Boserupian dynamic has been observed at the local scale by numerous case studies (Bilsborrow, 1987), but its assumption that innovation accompanies intensification applies less consistently, I think, to the *campesinos* and colonizers of marginal agriculture lands in Latin America, who continue to use crude agricultural practices (Schweigert, 1992) and have been neglected by official agricultural extension programs (de Janvry, 1981).

The Paso case study as well as the case of Panama's Azuero peninsula (Heckadon Moreno, 1981; McKay, 1973) suggest that, given an insufficiency in agricultural technology or innovation, *campesinos'* means of 'escape' from Boserupian pressures – their innovation – may be by extensification as much as by intensification. In the early 20th Century, mounting population pressure amongst *campesinos* of Panama's interior Los Santos province lead to the expansion of the area under agriculture, yet as forests were felled and population continued to mount this expansion was followed not by intensification but by extensification and emigration. Migrants spread over the nearby forest frontier of Tonsi until its forests were cleared, and by the post-war period, land use in Tonosi had also extensified such that emigration was again necessary. Migrants from Tonosi pushed toward the remaining forested frontiers of Bayano and Darién and are converting them to the same agricultural systems typical of the interior provinces. Intensification and farm-system changes are thus neither automatic outcomes of pressure nor easy achievements, and so long as a pressure valve such as the possibility of emigration exists intensification may be deferred. Further, the Boserupian thesis implies that it is the same population that progresses from stage one (long fallows) to stage five (sedentary multi-cropping). This, in turn, presupposes a degree of permanency in the population and that the original agriculturalists have the capacity to intensify. Yet, for a variety of reasons, the initial colonizers in an agricultural frontier may not successfully intensify despite pressures and attempts to do so. Upon their failure, other, relatively fewer 'secondary' colonizers may replace them with more extensive land uses, leading to net emigration, as discussed below. In conclusion, it appears that though the Boserupian thesis is sound, it does not describe well the dynamic of a tropical colonization frontier.

4.0 The Hollow-Frontier Theses

The hollow-frontier thesis (HFT), or '*colono* system', arguably better incorporates contextual and exogenous factors of LUCC in tropical frontiers to explain the ascendancy of extensive cattle production despite high demand for land. In particular, the HFT more fully considers the contextual, often exogenous, factors as they interact with the local context (Camara-Cabrales, 1999; Dagang et al., 2003; Heckadon Moreno, 1979; Heckadon Moreno, 1981; Heckadon Moreno, 1981a; Heckadon Moreno and McKay, 1984; Imbernon, 1999; McKay, 1973; Rudel et al., 2002). This section summarizes the HCT, presents supporting evidence and concludes with a critique of the thesis.

4.1 Summary of The Hollow-Frontier Thesis

The HFT is marked by a two-stage frontier settlement process (Heckadon Moreno, 1981). The first, 'extractive' stage is characterized by significant immigration into the colonization frontier and a resultant population expansion of typically poor, landless/land-poor subsistence agriculturalists. For example, Cabrita (1980) observes half a dozen households per day arriving in the Panama's Darién frontier. Land-to-population ratios are initially favourable, primary forest is felled and productive swidden cultivation of annuals predominates, as per the LCT. As colonizers establish usufruct land claims the number of farms and area cultivated expand at a hurried rate. Again, to illustrate, Cabrita (1980) observes that farm expansion in the Darién proceeded at an annual rate of 2500 hectares. As per the LCT, massive initial deforestation occurs with little regrowth, and fallows may be minimal if cattle are installed immediately after the exhaustion of cultivated soils previously under primary forest. Colonists may also fallow land in order to cultivate again once primary forestland is exhausted. In this case, yields and labour efficiencies both decline as due to deteriorating soil fertility and structure, as per mounting Boserupian pressure. Theile (1993) describes this point as the 'yield-efficiency scissor' for its role in defining the point after which radically different trends in LUCC eventuate.

In contrast to Boserupian expectations, the transition to the second, 'expulsive' stage of the hollow frontier is characterized by an extensification of land use. Factors responsible for mounting pressures on production, namely poor tropical soil, a lack of agricultural technology and inapt farm-systems (e.g., tenuous land claims, inappropriate agricultural technology, crowding, declining soil fertility, declining yields, declining labour efficiencies and pest problems) similarly curtail colonists' adaptation to these pressures (Lambin et al., 2003). Rather than fallow land and suffer opportunity costs and the possibility that another will claim the land in the meantime, colonists typically seek to install cattle to attain relatively secure cash incomes (Heckadon Moreno, 1981; Jones, 1990), in partial agreement to the LCT. More land is cleared to accommodate pasture expansion and to compensate for the land's decreasing productivity (Dagang et al., 2003), and forestland, fallow land, soil fertility and yields decline further. Pasture ascends as the predominate land use, often encouraged by cattle subsidies (Heckadon Moreno, 1981; Ledec, 1992) and cattle's socio-cultural allure (Heckadon Moreno, 1981a), and the frontier extends further. Simultaneously, land values increase with pasture expansion, especially as pasture provokes local land 'scarcity' amidst persisting poverty. Successful colonists and, frequently, wealthier ranchers from outside the frontier and with access to capital (e.g., agricultural or cattle credit) bid colonists off their land, induce them to 'sell out' or even expel them with threats of violence and litigation (Barbier, 2004). A period of population expulsion, farm consolidation and extensification is thus initiated. Though some early colonists remain in the frontier as share-croppers or renters (Thiele, 1993), as many as 30 percentmay fail to establish themselves and will sell out or abandon their lands (e.g., Green and Garcia de Paredes, 1969). Most regularly the expulsed households return not to their place of origin but push further into the frontier to repeat the process (Camara-Cabrales, 1999; Henkel, 1971). The expulsed may also migrate to urban areas (Brown et al., 1994) where they pool before re-launching into other colonization / logging endeavors or, alternatively, where they may be settled more permanently, an event which partly leads to outcomes described by the forest-transition thesis discussed below.

4.2 Evidence for The Hollow-Frontier Thesis

Colonization in Panama is organized around the 'culture of the pasture', a legacy of economic aspiration and social status amongst *colonos* owed to Spanish influence (Heckadon Moreno, 1979; Heckadon Moreno, 1981a). Considering this and the above-given description of the HFT it is not surprising that in Panama's Bayano frontier 58 percent of the 83 000 hectares of forest felled since the onset of colonization in the 1960s is currently pasture (a remaining 39% is 'degraded land', likely previous pasture, and 3% is cropland) (Adames et al., 2001). Table 1 and Figure 1 show the HFT dynamic as it progressed in the most heavily settled sector of the Bayano region since 1960. As predicted by the extractive stage of the HFT, between 1960 and 1970 the *colono* population surged while the number of cattle and area in pasture was nil (Figure 1). It was not until 1970-1980 that the area in pasture and the number of 'cattle farms'[2] surged in parallel with each other and with the population increase of the previous period. That the increase in pasture and cattle farms was far greater than the number of cattle installed suggests ranches were of a small scale and established by colonists as a supplement to cropping as they continued to access soils under primary and/or secondary forest. This perhaps applies up until 1990, when less fertile soils under young secondary regrowth were more commonly cropped and the yield-efficiency scissor was more strongly felt. After 1990, some 20 to 25 years since the first *colonos* arrived, the expulsive stage of the HFT is observable. Population decreases while pasture area and, importantly, the number of cattle increase steeply and in parallel, suggesting a population expulsion upon the onset of larger-scale cattle operations. It is difficult to decipher whether farm consolidation also eventuated. While the number of cattle farms unexpectedly increased upon de-population, this is largely due to farm subdivision. In any case, the increase was negligible relative to the steep increases in pasture and cattle populations, thus suggesting farm consolidation (or at least rapid pasture expansion (Dagang et al., 2003)) did take place in the hollow frontier after 1990. Notably, widespread deforestation occurred in the Greater Bayano Region over the period 1960-2000 despite negligible increases in population density (Table 1).

4.3 Shortcomings of The Hollow-Frontier Thesis in the Context of Colonization Fronts

Decades of colonization in tropical Latin America have repeatedly corroborated the processes of land-use and land-cover change described by the hollow-frontier thesis, and the thesis' shortcomings are notably few. I therefore present below two scenarios in which a hollow frontier's development may be altered into ways inconsistent with the thesis.

The HFT tends to assume a "one-off" decline in productivity upon deforestation. It also tends to assume a somewhat ubiquitous pasture front replacing decreasingly productive annuals cultivation. Yet Thiele (1993) and Maxwell and Pozo (1981) observe that colonists may choose to concurrently cultivate less productive and

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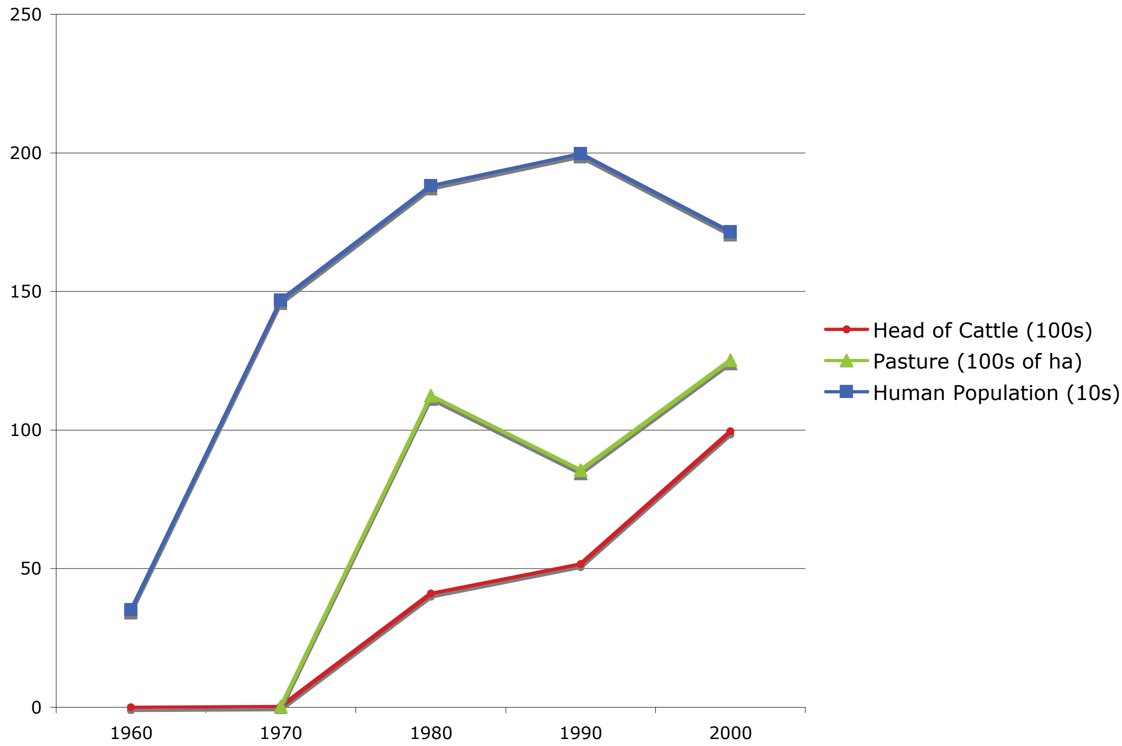
[2] 'Cattle farms' is a term used by Dagang et al. (2003). It is not defined, but can likely be interpreted as meaning either single plots or entire farm enterprises dedicated to cattle.

Figure 1 –Land Use and Population in the Southern Bayano Region, 1960-2000.



Source: Adapted from (Dagang et al., 2003)

inefficient soils from under secondary regrowth with more productive freshly cleared soils from under primary forest despite retaining access to additional areas of fertile soil under primary forest. This is an apparent irrationality and a departure from the HFT. Yet colonists may achieve a degree of labour complimentarily when simultaneously cropping both types of soil and are thus able to raise total output from familial labour (Thiele, 1993). Deforestation is thereby slowed, soil fertility may be maintained at a diminished level, and cattle's ascendancy is delayed indefinitely. Declining fertility is therefore not necessarily a precursor to the hollow frontier.

A hollow frontier may also experience revitalization within its core that reverses cattle's ascendancy in the landscape (Henkel, 1971). As with the Boserupain thesis, colonizers' use of herbicides and fertilizers may confound expected outcomes as otherwise uneconomical cultivation is made possible. Similarly, and as with the LCT, initial capital accumulation can lead to a more permanent form of agriculture through innovation, mechanization, the cultivation of perennials, or other means. For instance,

Table 1 – Rural Population Densities And Forest Cover For The Province of Los Santos and the District of Chepo (The Greater Bayano Region), Republic of Panama, 1960–2000.

	1960	1970	1980	1990	2000
	Rural Population Density (Residents per km²)				
Los Santos	16.5	16.7	15.4	16.5	17.7
Chepo	<1.0	2.2	2.6	3.8	4.3
	Rural Population				
Los Santos	70, 544	72, 380	70, 261	76, 947	83, 495
Chepo	4, 573	11, 881	13, 664	20, 174	22, 766
	Forest Cover (km² and % total area)				
Los Santos	†	186 (4.8%) [b c]	†	212 (5.4%) [c e]	279 (7.2%) [c]
Chepo	~4800 (90.4%) [a] †	†	†	3182 (61%) [d]	2731 (51.4%) [c]

Notes: The Greater Bayano Region incorporates the area from Chepo town to the Darién border, including all of the Comarca de Madungandi. See Figure 1 of the Introduction. Areas of Los Santos and Chepo are 3,867 km² and 5,308 km² respectively.

Sources:

Population Data: Derived from Controlaria (1991a, 1992a, 2001a, 2001b)

Forest Cover Data:

(a) Map-based estimation based on expert sources.

(b) Estimation for 1973.

(c) Author's Landsat satellite imagery-derived estimations.

(d) Satellite-imagery derived estimations by ANAM (2003)

(e) Estimation for 1988

† Cloud cover prohibitive of satellite image-derived estimations, or satellite imagery not available for the period

The Greater Bayano Region incorporates the area from Chepo town to the Darién border, including all of the Comarca de Madungandi

Maxwell (1980) observes that despite some land consolidation and social stratification, depopulation that accompanies the hollow frontier can be mitigated as less successful colonizers remain and supplement their own cropping with occasional wage labour.

Still, the exceptional outcomes in a hollow frontier from agricultural revitalization or the simultaneous cultivation of soils under primary and secondary forests rest on the assumption that cattle ascends in the landscape primarily due to its relatively suitability to infertile soils. It is true, however, that regardless of soil fertility cattle ranching may predominant in colonization frontiers primarily due to its profitability and security as well as its ability to complement other household resources or lack thereof (Coomes et al., in press; Patridge, 1984; Reardon and Vosti, 1995; Vosti et al, 2003). The aforementioned situations inconsistent with the hollow frontier are thus unlikely to be exceptions. Departures from the hollow frontier LUCC dynamic are likely to depend more on the attractiveness of pasture and cattle raising a use of land, labour and capital relative to alternatives.

5.0 The Forest-Transition Thesis

The1990s saw 40 percent of the world's nations experience net forestation (FAO, 2001). Many of these nations are poorer tropical nations previously characterized by rampant tropical deforestation culminating in the 1980s (FAO, 1993). This reversal has led Rudel et al. (2002) to ask whether a 'forest transition' – a national-scale transition from net deforestation to net forestation – might now characterize some of the tropical colonization frontiers that hosted so much deforestation during the 1980s. The following summarizes the forest-transition thesis (FTT) and presents evidence in its support. I then critique the thesis and suggest that its utility in a frontier setting is limited by its a-contextual formulation.

5.1 Summary of The Forest-Transition Thesis

The forest-transition thesis summarizes the historical relationship between economic growth, agricultural decline and reforestation in temperate developed nations (Walker, 1993). The theoretical basis for the forest transition given by Mather and Needle (1998) begins with spontaneous deforestation and cultivation of lands of varying productivity. Rudel (1998) posits that deforestation and cultivation is owed to increased economic activity amidst impoverishment, though in poor, forest-abundant tropical nations, poverty and land-scarcity alone have proven sufficient to induce this early phase (Heckadon Moreno and McKay, 1984). Settlers are "initially unable to perceive these variations in land quality" (Mather and Needle, 1998: 118) or, perhaps more realistically in the context of tropical colonization, they are restricted in their choice of land by circumstances (e.g., poverty, land hunger, lot allocation). Settler land uses – often a product of settlers' culture, origin and habit as much as local agro-ecological conditions –

are often not well suited to their new lands. A period of relative stability ensues, which is soon succeeded by a passive yet progressive 'land use-land quality adjustment' in which crop production relocates and concentrates on superior lands while marginal lands are abandoned. Superior lands remain deforested as agricultural production intensifies to meet an often growing demand for agricultural products while using less land than initially. Marginal lands reforest as their previous residents abandon lands and/or relocate. In this way a better spatial fit arises between agriculture, forest and land quality, and a forest 'turnaround' is achieved: the total cultivated area declines, total agricultural output remains constant and net reforestation results.

The FTT explains the forest turnaround event with reference to two economic processes: macro-economic urban-industrialization, and micro-economic forest scarcity (Mather and Needle, 1999; Rudel, 1998; Rudel et al., 2002; 2005; Walker, 1993). In the case of urban-industrialization, macro-economic growth promotes rural-to-urban migration of job-seeking farmers and decreases rural fertility (Rudel, 1998). In the short term, the removal of farmers from predominantly marginal lands allows for forests to recover on their lands. In the longer term, the absence of farm heirs and familial labour leads to farm-size contraction and forest regrowth as per the LCT. As populations of marginal farmers decline, their land may then be incorporated by neighbors as per the HFT, rented or abandoned. Agricultural industrialization associated with urbanization/industrialization also promotes the abandonment of marginal lands, while large-scale mechanization lowers the unit prices of agricultural goods below the level at which marginal farms can compete. Thus, growing markets for rural labour and farm produce quickly drive the land use-land quality adjustment.

In the micro-economic scenario, widespread deforestation as well as market demand for forest products induce price increases for forest products. This increase, in turn, leads to the increased felling of primary forests but also to the planting of woodlots and plantations (Salam et al. 2000). With government support, price increases alone can may promote net gains in total forest area, though probably only where widespread deforestation is not possible (Rudel, 1998; Rudel et al., 2005).

How well can a general thesis of economic change and reforestation describing the experiences of temperate nations apply to modern tropical regions? Urban-industrialization in poorer tropical nations differs from that in historical temperate countries, as do patterns of land use and markets for tropical forest products, agricultural products and labour. The concept of the 'road of many returns' helps bridge historic and modern contexts (Waters, 1997). This concept recognizes that contemporary tropical smallholders of even marginal lands are less willing than their temperate counterparts to abandon their lands outright given the precarious nature of urban employment as well as the ease of transportation. Smallholders follow a 'road of many returns' by maintaining off-farm employment, often seasonal in nature, in addition to a plot of land, thereby spreading risk and smoothing income over multiple ventures and maintaining a safe haven in the land. This strategy may allow for some reforestation with farm contraction, due to reduced pressure on the land; yet unlike the historic context, a smallholder is unlikely to allow reforestation without also considering income generating potential. Reforestation may therefore take the form of extended-period fallows mixed with crops, timber plantations, or tree crops. The road of many returns still allows marginal lands to 'reforest' as per the general FTT on the premise that their inhabitants seek off-farm employment first and most of all (e.g., Preston, 1990).

5.2 Evidence for the Forest-Transition Thesis

Sufficient country-level evidence exists to conclude that a forest transition is occurring in many nations, some of which are tropical. Trends in the FAO (1993; 2001) data described above are a prime example. Rudel (1998) tests both micro- and macro-economic explanations of the forest transition using measures of national forest cover as a proxy for forest scarcity and measures of urbanization and population growth as proxies for urban-industrialization. In both instances the indicators significantly predicted the direction of forest-cover change for 54 to 133 nations between 1922 and 1990[3], though the urbanization measure (% population urban or rural) was significant only during the post-war period. Rudel et al. (2005) also present strong country-level evidence for forest transitions occurring in the 1990s using measures of macro-economic performance (measured as GDP per capita as a proxy for rural labour scarcity) and forest scarcity (measured as forest as a percent of total land area as a proxy for price-induced reforestation). Combining both variables correctly predicted the direction of (de)forestation trends for 103 of 136 nations. Numerous historic examples of forest transitions in countries such as France, Scotland and New Zealand offer further credence to the thesis (Mather and Needle, 1998; Walker, 1993).

[3] The longitudinal analysis was conducted for various periods between 1922 and 1990. The initial period of 1920-1948 had a set of 54 nations, while the final period of 1980-1990 had 133.

Detailed observation of reforestation in tropical countries is needed to formulate a tropical forest transition particular to features of the modern tropics, such as climate, land use, poverty, economic security and urbanization. Yet despite regional-scale case studies of reforestation in Central and South America (Baptista and Rudel, 2004; Hecht, 2004; Klooster, 2003; Rudel et al., 2000, 2002; Southworth and Tucker, 2001; Zweifler et al., 1994), a distinct tropical forest-transition theory remains nebulous. This owes in part to the fact that many studies cannot observe LUCC in detail over more than a two or three decades at best and in part to the fact that the extreme diversity of contexts and outcomes within the tropics means that each case study seemingly speaks of unique events rather than a common transition (though see Rudel (2005) for the most complete synthesis to date). Notwithstanding the apparent lack of a common thread between many of the cases, evidence exists for the primary drivers of the forest transition in the tropics. Hecht (2004) observes an association between rural wage emigration and forest cover resurgence in El Salvador, as does Rudel et al. (2000) for poor, small-scale, marginal-land farmers in Puerto Rico. Baptista and Rudel (2006) observe forestation to be associated with regional industrialization in southern Brazil. Still, the exceptions to the rule, which appear not as aberrations but as important events unto themselves, confound efforts to synthesize a single tropical forest-transitions theory. For instance, Klooster (2003) observes reforestation coinciding with a shift away from agriculture and towards small-scale pottery manufacture, but he also observes selective deforestation as locals exploit nearby forests for wood fuel for their kilns, calling attention to institutional and economic aspects of forest use. In south-eastern Ecuador, Rudel et al. (2002) observe emigration and farm relocation amongst *mestizos* upon a price decline for traditional agricultural products, yet, owing to the predominance of cattle ranching, they observe little reforestation but appreciable deforestation as *mestizos* expanded their pasturelands into forest. In the communities of Shaur Amerindians, however, who hold fewer cattle but greater areas in horticulture, reforestation occurred more extensively and at different distances from the road. Unsurprisingly, ethnicity was a significant predictor of the likelihood and location of reforestation.

5.3 Shortcomings of the Forest-Transition Thesis in the Context of Colonization Fronts

Though correlational and historical country-level studies of the forest transition have identified important drivers of sustained reforestation, they impart limited knowledge of how or where a forest turnaround event might occur. Importantly, the fact that factors such as ethnicity, land-use patterns, institutional arrangements, and household resources also influence reforestation in tropical contexts suggests that the FTT describes reforestation in overly abstract terms that cannot appreciate variability and diversity likely to characterize forest transitions. In its nascent stages, a tropical forest transition is likely to be particular to market conditions, geographies, agricultural economies or societies and highly differentiated by preceding patterns of land use.

The forest-transition thesis tends to over generalize the expected forest-cover outcomes on the basis of the historic experiences of temperate nations (Perz, 2007). Though Grainger (1995) does not contest the universality of the thesis, in arguing that the forest transition must be preceded by a land-use transition[4] he highlights the intimate relationship between patterns of land use and subsequent forest-cover resurgence. I argue that the determination of the nature, extent and likelihood of a forest transition must be made in relation to the preceding land-use pattern and at the regional scale (cf. Zweifler et al., 1994). Throughout this thesis, I demonstrate that, upon relating the forest transition to preceding patterns of land use, a much greater understanding of the forest transition becomes possible. Particularly advantageous is the possibility of understanding how a forest transition may arise differentially from distinct patterns of land use, and how features of a particular pattern of land-use might be harnessed or 'piggy backed' to encourage reforestation. This approach allows us to understand how patterns of land use may impede a forest transition that otherwise might occur. The hollow-frontier dynamic of the Bayano-Darién frontier, discussed in this thesis, demonstrates both these points. Firest, depopulation and emigration that occur in hollow frontiers might beget reforestation (as per the forest transition) if not for the expansion of subsidized cattle ranches (Ledec, 1992) belonging to colonos. This thesis and other research (Berti, 1999; Vosti et al., 2003) suggest that promoting other land uses comparable to pasture in the hollow frontier may thus permit reforestation. Second, this thesis notes the insecurity and lack of economic alternatives faced by colonos and thus the unlikelihood that they will abandon their lands upon obtaining non-farm employment. Instead, the colono may follow a 'road of many returns' and supplement depressed on-farm income with intermittent off-farm work (Waters, 1997) while establishing impermanent and remunerative forest cover such as short-term plantations or extended fallows on lands the colono can no longer actively occupy (Rudel et al., 2002). Simultaneously, the decreased on-farm presence of the household may also

[4] In the land-use transition, deforestation becomes less and less a component of land use.

promote pasture within the household's land-use portfolio due to its labour-extensive and highly secure nature, so producing a middle ground between the hollow frontier and forest transition. Of course, colonos may also invest off-farm income into pasture expansion and preclude any reforestation, an outcome observed by this thesis.

In the context of tropical colonization frontiers, the micro-economic path toward the transition appears more promising in that greater prices for forest products may compete directly with pasture. Indeed, in the Bayano-Darién subsidized teak plantations have recently expanded over pasture in a manner suggestive of pasture's original ascent in the landscape. Elsewhere, reforestation has occurred differently, often in accordance to distinct patterns of land use (e.g., Rudel, 2005). Until the tropical forest-transition thesis is formulated relative to diverse patterns of land use, disparities in observations of reforestation across different contexts are likely to hinder the cohesion of a tropical forest-transition theory.

6.0 Conclusions: The Potential For Simultaneity Amongst The Theses

Two broad conclusions are drawn from this examination of the four theses of LUCC. First, each theses offers descriptions of LUCC that converge as well as diverge. Often they do both, and one thesis' account parallels another's only to diverge later.

Table 2 summarizes aspects of the four theses pertaining to LUCC and offers examples in which a particular thesis' description of LUCC mirrors that of another. At a simple level, likeness is apparent between the life-cycle thesis and the Boserupian thesis (Table 2 Row IV). Each utilizes the population-to-production ratio (or a variation thereof) as an indicator of land use and associated land-cover change. Upon surpassing some critical value of this ratio both theses indicates a tendency for farm expansion and productivity increases. At this point, however, the descriptions diverge. Differences in scale and variable(s) of interest (i.e., labourers vs. population) account for some divergence, but divergence arises more because of differences in the context and scale of observation (temporal and geographic): prolonged Boserupian land scarcity necessitates that households intensify, while the life-cycle thesis observes only episodic household production constraints.

Convergence and divergence also occurs between the Boserupian thesis and the hollow-frontier thesis. Row VII of Table 2 illustrates that both theses describe the same course of change until the point at which soil fertility declines critically – Theile's (1992) 'yield-efficiency scissor' (Section 4.1); subsequently, the theses diverge significantly. While the hollow-frontier thesis predicts farm consolidation and extensification, Boserupian theory assumes farm sub-division and intensification. Again, conditions particular to thesis' context explain the divergence; the Boserupian thesis presumes peasants' opportunity for further spatial expansion is limited, while the hollow frontier depends on such a presumption.

Finally, strong parallels are observed between the hollow-frontier thesis and the tropical forest-transition thesis. The extent to which these theses' stages of change approximate each other is uncertain, as the forest transition has not been specified well at the regional scale. Nonetheless, upon the depopulation of the frontier, the outcomes described by each thesis are commensurate and may, in fact, interact. Hypothetically, two possibilities support this potential intaction. First, the 'middle ground' between the between

the hollow frontier and the forest transition, characterized by contracted, partially reforested farms with fewer residents whom are more reliant cattle (Section 5.3). On the other hand, and in what is perhaps an alternate 'middle ground', the expansion of large teak plantations in lieu of ranches into the Bayano hollow frontier suggests a second avenue by which the two theses merge in the same landscape of LUCC (Section 5.3).

The convergence and divergence between the theses leads naturally to the second conclusion: that land-use and land-cover change is dynamic event that should be approached with multiple theoretical perspectives. Relatively minor variations in a single contextual feature in a frontier may produce large changes in how forest cover advances. As the forest-cover change varies with such contextual variations, so do the theses which describe the frontier's LUCC dynamic, such that numerous theses may apply to a greater or lesser extent as one dynamic gives way to another. For instance, should the extensive 'investment' land uses such as pasture inherent to life-cycle stages accumulate over but a few generations, population pressures more indicative of a Boserupian dynamic may also arise in the landscape. Similarly, Boserupain intensification may transition to a hollow frontier upon changes to settler mobility, soil fertility and/or cattle prices. Finally, a hollow frontier may witness a forest transition with changes in forest product prices or the attractiveness of cattle pasture relative to other land uses. Such illustrations are simplistic but suffice to make the point that the LUCC dynamics described by each thesis are transitory not only with respect to time but with respect to each other. Also, the theses are geographically nested within the other (Table 2), such that their simultaneous

Table 2 – Aspects of Land-Use and Land-Cover Change of Four Theses.

		Life Cycle	Boserupian	Hollow Frontier	Forest Transition
I	Geographic Scale	Household; Observable at regional scale	All scales save household	Regional, with direct link to household scale	Regional to national to sub-continental
II	Temporal Scale	One generation	One-to-multiple generations	Household: as little as 5 years Regional: 10-40 years	Historically, 50-100 years for full national transition
III	Principle Agents	Households	Households	Initially poor colonizers Later larger-scale, wealthier ranchers	Households Also: agents of urban-industrialization and forest product pricing
IV	Principle Factors	Household labour availability Consumer-to-labourer ratio	Agricultural-output-to-consumption-demand ratio Population pressure over agricultural land	Agricultural sustainability Land value / speculation Relative cattle price / costs	Off-farm employment Forest product prices (relative to cattle)
V	Trends in Agriculture	Oscillation between intensive annuals and extensive perennials / cattle	Step-like intensification Plot size and labour efficiencies diminish	Intensification, then progressive extensification Land consolidation and ascendance of pasture	Intensification, especially on high quality lands Abandonment or contraction and extensification on marginal lands
VI	Trends in Land Cover	Oscillation between deforestation and partial regrowth Oscillation of deforestation rates	Initial forest conversion Fallows replaced by scrub, then permanent cultivation Little to no forest regrowth	Initial conversion of primary forest, then of regrowth, if any Little to no regrowth	Nil regrowth over high quality lands; deforestation likely (Partial) regrowth over marginal lands
VII	Stages of Change	1. Intensive, subsistence swidden cropping 2. Farm diversification, expansion, extensification, investment 3. Farm contraction	1. Swidden cropping expands in spatial extent 2. Intensification without adaptation; continued under production 3. Critical soil fertility decline 4. Agricultural innovation, adaptation and intensification	1. Swidden cropping less frequent under primary forest, more under secondary 2. Intensification without adaptation; continued under production 3. Critical soil fertility decline 4. Exodus 5. Ranchers consolidate land	Unspecified Land use–land cover adjustment is gradual

consideration relative to a particular landscape such as a frontier adds detail to commonly employed analytical dichotomies such as local-regional or proximate-underlying (Geist and Lambin, 2002).

This chapter has argued that the four thesis of LUCC, often predominating at different geographic scales, may be envisaged as existing on a common spectrum of often-overlapping LUCC possibilities, differentiated principally by a relative few pivotal events or contextual features. As such, a multi-theoretical approach should be employed in observing land-use and land-cover change in order to incorporate transitions from one dynamic to another and produce a fuller characterization of landscape change.

Introduction to Chapter 2

Chapter 1 discussed how the dynamics described by four theses of land-use/cover change (LUCC) converge as well as diverge. Scale of observation is a crucial determinant of what LUCC dynamics are observable and how they converge or diverge. Dynamics observable at finer spatial scales cannot necessarily be assumed to exist in an aggregate form at coarser spatial scales. Rather, at coarser scales of analysis, new drivers of LUCC may be observed with correspondingly distinct LUCC dynamics.

Chapter 2 discusses regional-scale LUCC in the Bayano-Darién frontier and other 'hollow frontiers' of Latin America to critique a macro-scale projection of tropical reforestation based on micro-scale relationships. Specifically, while anticipated rural depopulation suggests tropical reforestation may soon characterize Latin America on the basis of national-scale population-deforestation correlations, Chapter 2 argues that, at scale of the forest frontier, where most forest and deforestation exist, depopulation may associate with continued deforestation.

Chapter 2 also illustrates the diverse associations between context and particular LUCC dynamics. Chapter 1 outlines how LUCC dynamics or theses that converged to a point may subsequently diverge as human and environmental contexts shift and encourage one dynamic over another. Thus, LUCC projections made on the basis of assumed continuity of a particular dynamic may fall short as contextual changes accumulate and ultimately define a new context governed by a new dynamic. Chapter 2 demonstrates this point with reference to LUCC in forest frontiers at different stages of settlement. Remote and recently-settled frontiers may experience reforestation as their populations decline; yet in older and more proximate frontiers, characterized by different contexts than remote frontiers, depopulation may instead associate with deforestation. Chapter 2's conclusion elaborates that of Chapter 1: LUCC analyses must employ multiple theoretical perspectives, as must projections of LUCC to account for accumulating changes in environmental and socio-economic conditions that in turn encourage shifts in LUCC dynamics.

CHAPTER 2

FEWER PEOPLE MAY NOT MEAN MORE FOREST FOR LATIN AMERICAN FOREST FRONTIERS[5]

Sean Sloan

In 'The future of tropical forest species' Wright and Muller-Landau (hereafter WML) (2006: 287) assert that "[h]umans cause deforestation, and humans living in rural settings have the greatest impact on extant forest area in the tropics". They point to a positive correlation observed between human rural population density and deforestation to support their assertion. WML correlate rural population densities for 45 Asian, African and American countries with the proportion of 'potential' forest remaining in each, subsequently explaining 76 percent of deforestation to date. WML then project future net tropical deforestation until 2030 using rural population projections. On the basis of the population-deforestation relationship, WML conclude that anticipated declines in rural populations via urbanization will herald net afforestation, particularly in Latin America.

Drawing from the social science literature on land-use/cover change in tropical forests, I challenge WML's key analytical assumption that declines in rural population density after deforestation has occurred will result in widespread afforestation. WML (2006: 295) do anticipate such challenges with their caveat that should land use become

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less labour intensive *in future*, then their predictions will be overly optimistic. WML fail to appreciate, however, that in neotropical forest frontiers: (1) regrowth suppression via land-use extensification is a characteristic outcome of population decline, and (2) exogenous drivers of land-cover change are increasingly diminishing the role of local population in such change. These tendencies are both long established and ongoing, so challenging WML's predictions *from their onset.* I focus primarily, but not exclusively, on Latin America, as WML view this region most optimistically as an illustration of their expectations.

WML's predictions reflect the broad assumptions of the forest-transition thesis, a summary explanation of the convergence of afforestation, urbanization and agricultural land abandonment based on historical, temperate-nation precedents (Mather & Needle 1998; Rudel 1998, 2005). In this WML neglect Latin America's primary drivers of deforestation, its rural populations' distributions and redistributions, and the increasing influence of non-local drivers of land-cover change. These factors have a profound influence on deforestation rates and our ability to predict them via population figures. This is apparent upon considering neotropical forest frontiers, such as Panama's Darién, Guatemala's Petén or Brazil's Amazon, where much forest cover remains and deforestation rates are high.

The Darién frontier comprises less than 20 percent of Panama's national area but approximately 40 percent of its forest cover (ANAM 2003). During the 1970s peasants colonized the region, claiming land and opening forest for small agricultural plots (Wali 1989). Forest conversion for short-term gains in livelihood characterized this early 'extractive' stage of frontier development (Heckadon Moreno 1981). Populations were unable to maintain yields and efficiencies, and many subsequently abandoned lands or sold out to larger interests (*cf.* Thiele 1993). Notably more successful colonists remained by extensifying land use, namely by converting their land to pasture. An expulsive stage inevitably resulted as relatively fewer expansive landholders replaced more numerous smaller farmers.

This expulsive settlement stage contradicts WML's assumptions regarding the population-deforestation correlation. During this stage, 30 percent or more of an agricultural population may abandon their lands while those who remain suppress regrowth by expanding over the formers' lands and into surrounding forest. In the southern Bayano Region, the Darién's most populous front, this stage has been underway since 1990; between 1990 and 2000, the population decreased by nearly 20 percent, but pasture area increased by nearly 50 percent and the number of cattle by 100 percent (Controlaria 1991a, 1991b, 2001a, 2001b). The Bayano Region thus became a 'hollow' frontier as declining population density coincided with regrowth suppression.

The concentration of remaining neotropical forest in frontiers isolated from most population also makes problematic WML's use of national-scale correlations to predict deforestation. Table 1 presents forest cover and rural population for the Panamanian district of *Chepo*, encompassing the Bayano frontier, and for the interior province of *Los Santos*. Population pressure mounted in *Los Santos* during the post-war period, and by the 1960s *Santeños* had begun migrating cross-country into Bayano's dense forests (McKay 1976; Heckadon Moreno 1981). Table 1 demonstrates that observed regional-scale dynamics accord poorly with WML's aggregate-scale assumptions. In *Chepo*, a mere increase from 3.8 to 4.2 residents per km^2 coincided with *451* km^2 forest cleared (*8.5% of the* total area) between 1990 and 2000, a seemingly disproportionate outcome until one recalls that, at the frontier, ongoing emigration coincides with deforestation. Contrastingly, in the crowded *Los Santos,* greater increases in density have coincided with steady *afforestation* since 1970. Thus, and particularly in the case of the frontier, the tabled data are not only distinct from each other *in nature* but are distinct from what WML's national-scale correlations suggest are necessary for similar levels of deforestation (their Fig. 2). In fact, the population densities of *Chepo* are negligible, averaging 2.7 rural residents per km^2 for the period 1960–2000, yet there, nearly *2000* km^2 *(37% of the total area)* have been deforested. The explanation for such discrepancies lies *not* with population but rather with the specific population-deforestation relationship between drivers of land use and outcomes on the frontier (*e.g.,* Perz & Skole 2003), mediated by socio-economic factors and discernible only through regional-scale correlation analysis (*e.g.,* Rudel & Fu 1996).

The hollow-frontier dynamic is evident throughout Latin America. Since the 1970s it has consistently typified land-cover change from Brazil (Brown *et al.* 2004; Fearnside 2001; Foweraker 1981; Simon & Garagorry 2005; Wood & Skole 1996) to Bolivia (Hecht 2005; Stearman 1983; Steininger *et al.* 2001; Thiele 1993) to Colombia (Ortiz 1984) to Central America (Jones 1989) to Ecuador (Pichón 1997; Rudel *et al.* 2002) to Mexico (O'Brien 1999) and beyond. The ubiquity of the dynamic challenges WML global analysis, for theirs is merely an aggregation of already overly aggregated national-scale data (Table 1). Today, globalization is bolstering the hollow-frontier dynamic by promoting various land uses other than pasture: witness the consolidation of ranchland

Table 1 – Rural Population Densities and Forest Cover for The Province of Los Santos and The District of Chepo (Greater Bayano Region), Republic of Panama, 1960–2000.

	1960	1970	1980	1990	2000
			Rural Population Density (Residents per km²)		
Los Santos	16.5	16.7	15.4	16.5	17.7
Chepo	<1.0	2.2	2.6	3.8	4.3
			Rural Population		
Los Santos	70, 544	72, 380	70, 261	76, 947	83, 495
Chepo	4, 573	11, 881	13, 664	20, 174	22, 766
			Forest Cover (km² and % total area)		
Los Santos	†	186 (4.8%) [b c]	†	212 (5.4%) [c e]	279 (7.2%) [c]
Chepo	~4800 (90.4%) [a] †	†	†	3182 (61%) [d]	2731 (51.4%) [c]

Notes: The Greater Bayano Region incorporates the area from Chepo town to the Darién border, including all of the Comarca de Madungandi. See Figure 1 of the Introduction. Areas of Los Santos and Chepo are 3,867 km² and 5,308 km² respectively

Sources

Population Data: Controlaria (1991a, 1992a, 2001a, 2001b)

Forest Cover Data:

(a) Map-based estimation based on expert sources.

(b) Estimation for 1973.

(c) Author's satellite imagery-derived estimations.

(d) Satellite-imagery derived estimations by ANAM (2003)

(e) Estimation for 1988

† Cloud cover prohibitive of satellite image-derived estimations, or satellite imagery not available for the period

into pineapple plantations in Costa Rica, or the clear tendency for agro-industrial soy to succeed pasture in Brazil (Brown 2005). Such are 'neoliberal frontiers' – a 'kind of market and technological triumphalism' that exaggerate the hollow-frontier dynamic (Hecht 2005: 376, 397). Depopulation may continue even among those groups remaining from earlier periods of emigration (Fearnside 2001), but now more regrowth is suppressed over even greater expanses by increasingly exogenous actors. As a result land-cover change becomes even less explicable by local population dynamics.

The Bolivian Amazon provides an example. Prior to Bolivia's neoliberal reforms commencing in 1985, the deforestation rate in its '*Tierras Bajas*' was 0.45 percent per year, divided equally between slash-and-burn farmers and industrial agriculturists (Steininger *et al.* 2001). Deforestation quickened as the reforms deepened, yet only among industrial agriculturalists (Vilar & Kupfer 1995), reaching 5 to 6.3 percent per year (Steininger *et al.* 2001), to which a displaced population contributed very little. Among peasants and colonists – the rural residents that concern WML – annual forest clearings declined by ten percent (3480 ha per year) and cropping areas (in corn and rice) by 50 percent (28,700 ha) from the culmination of the reforms in 1994/1995 to 2000 (Hecht 2005). Simultaneously, annual clearings among agro-industrial and large-scale Mennonite 'rural residents' increased by at least 25 percent (a comparably huge 69, 212 ha per year) and cropping areas in soy and sunflower continued to rise (Hecht 2005; Steininger *et al.* 2001). Over the period 1986–2000, some 1, 604, 010 hectares, or 87 percent of forestland converted to agriculture, ultimately passed into large-scale, 'successive' industrial and Mennonite agriculture (Hecht 2005). The growing role of non-local actors cannot be understated – by 2000, three quarters of the area in soy, representing 60 percent of the total area cleared, was foreigner operated (Hecht 2005). Again, despite slash-and-burn farmers' diminished presence, regrowth was suppressed more extensively as successive land uses maintained previously cleared land in increasingly wide-open expanses (Steininger *et al.* 2001).

The growing influence of non-local drivers of land-cover change is expected to perpetuate such a dynamic in coming years (Rudel 2005). Increasing demand for meat and (feed) grains, both at home and abroad but particularly by newly affluent nations, is expected to favour further expansion into neotropical frontiers rather than agricultural intensification, owing to a land abundance, prevailing farm systems and demographic and social conditions which favour expansion (Alexandratos 1999). For Latin America, the International Food Policy Research Institute speaks of a 'Livestock Revolution' as no less than the Green Revolution when describing the anticipated 80 percent growth in absolute demand for meat or the 45 percent growth in per capita demand for meat coincident with a 340 percent increase in meat exports by 2020 (Delgado *et al.* 1999; Pinstrup-Anderson *et al.* 1997, 1999). Pasture will be ascendant *and* increasingly managed by non-local enterprises (Delgado *et al.* 1999). Contrary to WML, the very urbanization hoped to diminish pressure on forests may fuel such 'revolutions' as the adoption of meat-heavy urban diets coincides with increased rural land availability (Browder & Godfrey 1997).

Research to date on land-use/cover dynamics indicates that population alone predicts afforestation poorly because, contrary to WML's assumptions, it has little direct or consistent bearing on deforestation, '*phenomenologically*' or otherwise (Carr 2004; Geist & Lambin 2002; Lambin *et al.* 2001). To illustrate: Wood and Skole (1998) link satellite imagery of deforestation to municipal-level census data for the entire Brazilian Amazon. At this finer resolution, population density displays only a weak relationship with deforestation. 'Rural immigration density' displays a stronger relationship, though it quickly declines as density, a proxy for slash-and-burn agriculture, becomes increasingly uncharacteristic of frontier deforestation over time. Indeed, upon disaggregating 'cleared land' into 'pasture' and 'slash-and-burn' areas, the later proved insignificant and predicted no more deforestation than the former which, aside from being the strongest predictor by far, relates inversely to forest regrowth and population density. Thus, where the geographic and temporal scale of analysis coincides with that of deforestation, the population-deforestation correlation weakens considerably. Where the correlation is significant at forest frontiers, it is often only fleetingly so as deforestation assumes a land-extensive character over time.

Importantly, where institutional, economic or contextual factors are incorporated into the analysis, population-deforestation correlations are found to be spurious (Angelsen & Kaimowitz 1999) or even counter-intuitive (Rudel *et al.* 2005). In sparsely forested Kenya, for instance, Lamb and Gilmour (2003: 86-7) observe *increasing* tree cover with increasing rural population density. Indeed, woody biomass *planted* in farmland exceeds that of national forests, owing to rural residents' secure land tenure and high demand for wood products. Perz and Skole (2003) observe the converse at the municipality-scale in the Brazilian Amazon. In remote, sparsely populated municipalities tenure insecurity amidst forest abundance correlates negatively with forest regrowth (significant at $p<0.01$) – residents hedge anticipated losses of land by clearing more than necessary while being unwilling to invest trees in insecure property. In more populous, less forested Brazilian municipalities the relationship is again inverted – tenure insecurity correlates with *more* forest regrowth (significant at $p<0.01$), now owing to changing land use and higher farmer turnover. In sum, variables that determine rural residents' afforestation potential have inconstant relationships with changing population densities, leaving population as a poor predictor of forest cover over time and between regions.

It must be said that the debate concerning rural depopulation and forest-cover resurgence is one in which both sides appear to be correct, but only partially. Clearly, forests will not fell themselves in humans' absence, and WML correctly highlight the possibility for tropical reforestation upon rural depopulation. What this debate needs most badly is a regional refocusing commensurate with the scale of land-use patterns and a careful consideration of such patterns. Yet it is equally clear that deforestation does not require high population densities, and that reductions in population density will not necessarily reduce deforestation. In Latin American frontiers, rural population density does not necessarily correlate with deforestation, and may correlate inversely over time. The corollary is that urbanization and rural depopulation may not necessarily result in the anticipated forest recovery, again with potential perverse effects. For a genuine forest transition, urbanization will have to capture not only the slash-and-burn variety of rural residents but also the more expansive interests that succeed them. This may not be possible where non-local interests are the successors. As it is, population densities at the initiation of deforestation in tropical frontiers are often greater than those found in the hollow frontiers afterwards (Heckadon and McKay, 1984). Therefore, the population-forest cover relationship from one period in time should not be directly applied to projections of future forest cover. Likewise, population-forest cover relationships at the national scale offer little insight into what is happening at the frontier. As most tropical forest of Latin America is found in frontiers, the fact WML's national-scale observations concerning population – a *proximate* driver of land-cover change (Geist & Lambin 2002) – are not observed at the frontier scale greatly qualifies their predictions. Such qualifications may average out over the very long term and at the very large scale; yet at the scale of the event in question such considerations are critical to theorizing a forest transition applicable to the tropics.

Introduction to Chapter 3

Chapter 2 emphasizes consideration of regional-scale pathways of land-use/cover change (LUCC) in relation to projections and analysis of tropical reforestation. No projection or understanding of tropical reforestation will be complete unless based upon knowledge of pathways of LUCC preceding reforestation. Different pathways of LUCC will define different pathways of reforestation. Further, as changes to environmental or socio-economic conditions accumulate over time, new LUCC dynamics may overtake previous dynamics, changing the likelihood and nature of reforestation and confounding simple projections of change.

Chapter 3 provides evidence for these points in analyzing tropical reforestation in the Bayano-Darién relative to the preceding pathway of pasture expansion and deforestation, termed the 'hollow-frontier dynamic' in Chapter 1. Chapter 3 discusses the spatial trends, nature and likelihood of tropical reforestation in the Bayano-Darién hollow frontier, and notes distinctions relative to contexts defined by other LUCC dynamics.

As an extension of Chapter 1, Chapter 3 also explores the potential for simultaneity and succession between the hollow-frontier pathway and the forest transition pathway of reforestation. Though antithetical in outcome, opportunities for the forest transition tend to occur simultaneously and successively to the hollow frontier dynamic. Reforestation can be simultaneous to and successive of the hollow-frontier landscape as the pattern and drivers of reforestation mimic those of forest-to-pasture conversion inherent to the hollow frontier.

CHAPTER 3

A FOREST TRANSITION IN A HOLLOW FRONTIER IN EASTERN PANAMA: THE POTENTIAL FOR SIMULTANEITY AND SUCCESSION

Sean Sloan

1.0 Introduction

The 1980s witnessed rampant deforestation in the global tropics, particularly in Latin America (FAO, 1993). Over the 1990s, however, deforestation rates declined in all tropical regions of the world save for East and West Africa (FAO, 1993; FAO, 2006), and a select few tropical countries exhibited net reforestation (Arroyo-Mora et al., 2005; Lugo and Helmer, 2004; Rudel, 2005: 122-38; Rudel et al., 2000; Sánchez-Azofeifa, 2000). Researchers are increasingly observing landscapes with renewed and enduring forest cover throughout Central and South America (Aide et al., 2001; Baptista and Rudel, 2006; Bauch, 2007; Chazdon, 2003; Collier et al., 1994; Hecht, 2004; Klooster, 2000; Klooster, 2003; Moran et al., 1996; Rudel et al., 2000; Schelhas, 1996; Southworth and Tucker, 2001; Zweifler et al., 1994), leading Hecht (2004: 64) to suggest that the 'doomed forest' narrative for Central America may require revision. Such seemingly *transitional* resurgences of forest cover recall earlier recoveries of temperate nations' forests, known generally as 'forest transitions' (Mather, 1992; Mather and Needle, 1998). The positive environmental implications of forest-cover resurgence (Rudel et al., 2005: 23-4), namely carbon sequestration (Achard et al., 2004: 8), soil and water protection (Kramer et al., 1997), and biodiversity and habitat restoration (Brook et al., 2006; Lamb et al., 2005; Lugo, 1997; Schelhas and Greenberg, 1996; Wright and Muller-Landau, 2006), have lead researchers to intensify attention on the potential for and mechanisms by which tropical nations undergo forest transitions.

The increasing complexity of forest-cover change since the 1990s has complicated the new focus on reforestation. While the influence of penetration roads, colonization projects and subsidized agricultural credit on forest destruction in Latin America has declined as states have withdrawn from their formerly prominent role (Rudel, 2005: 37-9, 60-2), globalized and pluralistic forces for tropical forest-cover change have filled the void with wider array of impacts (Brown et al., 2004; Hecht, 2005; Rudel, 2007; Steininger et al., 2001). These globalized dynamics interact with recent trends toward forest-cover resurgence as well as with localized forces to produce especially diverse and novel dynamics of forest-cover change. Taken together, trends in forest-cover change (FCC) since 1990 have not only become more complex but more *simultaneous* as well. More than ever, *pathways* of forest-cover change – trends that verge on self-perpetuation as drivers, outcomes and agents reinforce each other – now complicate each other's trajectories by overlapping and producing, if only temporarily, hybrid patterns of change. Such patterns may characterize the 'turnaround point' of the forest transition, the juncture at which increasing trends in reforestation meet and then exceed declining trends in deforestation.

In Panama, new laws have spurred afforestation that has carried some regions to the 'forest-turnaround' point. Concerns over deforestation culminated in the Reforestation Incentives Law of 1992, known generally as Law 24[6], which provides generous financial incentives for those who afforest. Specifically, Law 24 offers (a) subsidized credit for the establishment of tree plantations, (b) subsidies to manufacturers that export plantation-timber products, (c) tax exoneration for direct and indirect investment in afforestation, and (d) tax exoneration with respect to timber sales, property acquisition and transfers, and the importation of materials. Between 1992 and 2004 slightly more than 46,000 ha were afforested in Panama (ANAM, 2006), much of this by international timber corporations with interests in export markets. The 33,000 ha afforested between 1992 and 2000 (ANAM, 2006) represented approximately nine percent of the total area deforested over the same period (ANAM, 2003: 73, Appendix

[6] The full name of the law is actually Law 24 of November 23 1992. Subsequent amendments include: Resolution Number AG-0151-2000, the Executive Decree 89 of June 8 1993, Article 80-C of the Executive Decree 170 of October 27 1993, which curtails some financial incentives inherent to Law 24 subsequent to the year 2002, and the Fiscal Reform of January 2005 in which a series of incentives of the original law were eliminated. Spanish text of the law and its amendments are available from the author or from http://www.anam.gob.pa/forestal/index.html

3). This proportion likely underestimates the present-day contribution of plantations given that many foreign plantation interests may have expanded subsequent to establishment and that the annual increments in area afforested have continued since 2000 while deforestation has likely slowed. Regardless, such afforestation cannot counter deforestation in all respects. Law 24 defines "reforestation" only as the planting of "forest species" and therefore does not differentiate between mixed stands of native species and exotic-species monocultures. It is therefore unsurprising that ~77 percent of the area afforested nationwide is in teak (*Tectona grandis*) (ANAM, 2006) – an exotic, ecologically inferior species (Healey and Gara, 2003) from South East Asia. Indeed, in the Bayano-Darién agricultural frontier of Eastern Panama, where afforestation has been concentrated, the area in teak is approximately 99 percent of the area afforested.

Timber-plantation expansion in the Bayano-Darién frontier has resulted in a forest-turnaround dynamic that could prelude a wider forest transition therein. Yet the presently limited understanding of the forest transition precludes an appraisal of the potential for this turnaround. Generalizing and even universalizing tendencies of the forest-transition theory (Perz, 2007) overlook the particularities of regional-scale pathways of tropical land-use/cover change that may precede a forest transition. The gains made in corroborating key correlates of the forest transition at the aggregate scale (Rudel, 1998; Rudel et al., 2005) have little utility in suggesting the undoubtedly varied likelihood and potential extent of reforestation within regions experiencing distinct pathways of land-use/cover change. This chapter responds to these shortcomings by examining the forest-turnaround point in the Bayano-Darién, an agricultural frontier characterized by the 'hollow-frontier pathway' of pasture expansion and deforestation commonly found in Latin America. The paper answers the following questions: (1) What is the likelihood, nature and potential extent of a forest transition within such an context? (2) How does a forest transition grow out of a hollow frontier? (3) What is the potential for simultaneity and succession between the forest transition and preceding patterns of land use? and (4) What agents and drivers propel and impede the transition in the frontier? The following section describes the hollow frontier and the forest transition in greater detail. The Bayano-Darién context and the study methodology are then described, and the results presented. This paper observes simultaneity and succession between patterns of deforestation and reforestation in the frontier, and concludes that re-focusing analysis on regional-scale pathways of land-use/cover change preceding forest transitions promises better understanding of both reforestation events and the forest-transition theory.

2.0 Pathways of forest-cover change

Forest-cover change does not merely imply a difference in forest extent, nor is it simply the result of deliberate choices of present-day agents of change (peasants, governments and commercial interests). Rather forest-cover change follows a rough path and pattern laid by the previous decisions of forest users as much as by present-day actions of contemporary agents. In an unintentional symphony of action, previous generations utilized the natural and economic resources at their disposal to formulate particular 'life-paths', be they the livelihood strategies of a forest-dwelling peasant or the five-year plan of a logging company. These strategies interact and solidify over time to produce a particular pathway of forest-cover change – a trajectory exhibiting its own spatial pattern and persistence. Over time, forest users pass to their successors their livelihood systems, sunk costs and assets implicit to their pathway of forest cover while also passing them a new, altered set of natural and economic resources. Successors, therefore, "drawing on the simultaneously enabling and constraining hand of the old" (Molotch et al., 2000: 791), perpetuate the pathway of forest-cover change they inherit but carry it forward on different terms. As these 'different terms' accumulate, old pathways may give rise to new ones. It is uncertain, however, whether new pathways develop gradually from old ones or progressively endure pressures until suddenly 'flipping over' into a new dynamic. This section describes two contrary pathways of forest-cover change: the hollow-frontier and the forest-transition. The fact that each pathway depends on similar factors yet results in wholly different forest-cover change outcomes begs the question of whether reforestation in a hollow frontier is possible and, if so, how. (Throughout this chapter 'reforestation' refers to expanding forest cover over previously forested land, while 'afforestation' refers to purposefully planted tree cover).

2.1 The hollow–frontier pathway of deforestation

In Latin America, smallholders' colonization of forests, their subsequent expansion of pasture and their ultimate displacement deeper into the forest frontier characterizes land-cover change (Jones, 1988; Jones, 1989; Jones, 1990; Ortiz, 1984;

Rattner, 1988). Termed the *hollow-frontier pathway*[7] for its tendency to result in sparsely populated denuded expanses, it is marked by two stages of development.

Rapid immigration into the forest frontier by land-hungry agriculturalists marks the onset of the first, 'extractive' stage (Heckadon Moreno, 1981). Land-to-population ratios are initially high as colonists (*colonos* hereafter) convert forests to small agricultural plots. Substantial deforestation results while regrowth is uncommon as households convert forest to agriculture and then cultivated lands to pasture. In time, the ratio of unclaimed land to population becomes less favourable, forest reserves become less abundant, and yields and labour efficiencies decline as *colonos* increasingly cultivate less fertile fallow lands. Theile (1993) describes this point as the 'yield-efficiency scissor', after which time the subsequent, 'expulsive' stage gains ascendancy. Land-use extensification, depopulation, land consolidation and continued deforestation characterize this second stage. Poorer *colonos* with limited opportunities for expansion may capitalize on the now increased value of their landholdings by selling out to those eager to expand their own pasture. In other cases, well-financed urban or international interests may buy out *colonos* to establish large commercial ranches (Barbier, 2004). In either instance, landholdings become increasingly extensive and consolidated and farms become more capital intensive.

The permanency of the hollow frontier depends on the continued predominance of an extensive land use such as pasture. This condition is common across Latin America (e.g., Foweraker, 1981; Jones, 1989; Ortiz, 1984; Stearman, 1983; Thiele, 1993) and within Panama (Dagang et al., 2003; Partridge, 1984). As foreign enterprises have come to play an increasing role in forest-cover change in Latin America (Hecht, 2005; Rudel, 2007), other extensive land uses, such as mechanized soya, have also characterized the hollow frontier (Brown, 2005; Fearnside, 2001; Sloan, 2007). The hollow frontier is enduring but may abate or shift character with off-farm employment (Bauch, 2007), emigration and labour scarcities (Preston, 1998) and declines in the price of beef and in the accessibility of cheap credit (Arroyo-Mora et al., 2005; Sánchez-Azofeifa, 2000). As this chapter demonstrates, reforestation incentives such as those of Panama's Law 24 may also promote a transition towards reforestation in the hollow frontier.

[7] Also known as the *colono* system or the peasant-pioneer cycle.

2.2 The tropical forest–transition thesis and forest 'turnaround' points

The forest-transition thesis provides a summary explanation of temperate-nation reforestation over the last 150 years (Mather, 1992; Mather and Needle, 1998; Walker, 1993). In the eighteenth and nineteenth centuries, economic expansion in temperate nations was associated with deforestation as farmers capitalized on growing markets (Walker 1993). As economies industrialized, rural labour was drawn toward urban centers. Over time, this transfer of labour allowed forests to selectively recover former agricultural lands. Forests recovered predominantly marginal farmlands while prime agricultural lands remained cleared and hosted increasingly intensive cultivation in what Mather and Needle (1998) refer to as the 'land-use–land-quality adjustment period'. In this way, countries passed a critical 'forest turnaround' point: after long periods of net deforestation, secondary forests began to characterize marginal areas until, ultimately, net reforestation became widespread and enduring.

Most accounts of the forest transition point to rural emigration and off-farm farm employment as key drivers, and observations for tropical nations appear to affirm their role. As in Puerto Rico, emigration and off-farm employment may lead to the abandonment of farmland (Rudel et al., 2000) and often coincide with industrialization. Emigration and off-farm employment may also diminish rural labour availability, causing landholdings to contract and forest cover to expand (see Rudel, 1998; and Rudel et al., 2005 for macro analysis using proxies for rural labour shortage) (see McCracken et al., 1999b; and Perz and Walker, 2002; and Walker et al., 2002 for the effects of household labour availability on landholdings). As in South East Asia, agricultural intensification may drive reforestation by encouraging farmers to concentrate cultivation on their better lands, thereby allowing their marginal lands to reforest (Rudel, 2005: 139-54). The productivity increases that accompany agricultural intensification may also drive down the price of agricultural goods, thereby reducing the viability of marginal farms and obliging marginal farmers to search for alternative livelihoods, furthering trends toward emigration and off-farm employment. In an alternative avenue toward the forest transition, forest scarcity stimulates demand for forests products that in turn raises forest-product prices and thus stimulate the expansion of forest plantations and woodlots (see Foster and Rosenzweig, 2003; Lamb and Gilmour, 2003; Salam et al., 2000 for localized examples) (see Rudel et al., 2005 for a cross-national example). Bangladesh, China and India exemplify this plantation-lead forest transition. One should not consider these factors deterministically, however, as many exceptional and counter-intuitive effects have also been observed: for instance, with respect to rural emigration (Rudel et al., 2002) or to agricultural intensification and rural wage increases (Foster and Rosenzweig, 2003). Rather, like land-use/cover change in general (Lambin et al., 2003), forest transitions are conjoint and contingent events that depend on the coincidence and combination of numerous factors within a given context.

Grainger (1995) argues that the forest turnaround point represents the boundary between the onset of a forest-replenishment period and the end of a land-use transition during which less and less forestland is converted to other land covers. In some cases, such as that of the USA, the overlap between these the land-use transition and forest replenishment period is brief and replenishment assumes predominance soon after the land-use transition, though in other cases, such as that of the UK, replenishment may be very protracted indeed. Grainger (1995: 244) argues that this delay arises because "stabilsing national forest cover and then increasing it are actually two separate national land use processes with different underlying mechanisms", and that the land-use transition must first terminate before the forest transition may truly begin. I would argue, however, that these two transitions actually overlap. Where these separate processes first coincide, an instable equilibrium rather than an immediate forest transition may result, within which initial forest-cover change in any direction is likely to be gradual and prone to reversal. Only upon the addition or, more likely, accentuation of a 'key factor' might the instable equilibrium shift into a forest transition.

At the initiation of the forest-turnaround point, factors associated with deforestation may also associate with incipient pathways of forestation. As such, the accentuation of these factors helps to promote reforestation. For instance, in India and Nepal, high rural population densities helped precipitate the destruction of forest fragments during the 1980s (Bajarcharya, 1983). With Joint Forest Management (JFM) agreements (Hussain et al., 1999) between rural communities and government during the 1990s, however, more populous communities generally protected and restored nearby forest more effectively than more sparsely populated communities[8] (Agrawal, 2000; Fox, 1993). Similarly, in South East Asia small-scale sedentary agriculture was associated deforestation but, with intensification, small-scale agriculturalists lead the way to reforestation. As agriculturalists intensified cultivation on better lands they allowed

[8] Rudel (2005: 135-6) qualifies this point by suggesting that more populous communities may also be more favourably located and therefore may have greater access to JFMs than remote communities. Remote communities, in contrast, likely experience the open-access conditions that encourage deforestation more than populous, centrally located communities.

marginal lands to reforest (Kummer et al., 1994; Müller and Zeller, 2002; Sikor and Truong, 2002) or planted them in tree crops (Tachibana et al., 2001). Similarly, intensified agriculture in the lowlands attracted labour in the form of nearby shifting cultivators, thereby reducing forest clearing due to swidden agriculture in the highlands (Schively and Martinez, 2001). Thus, in both India / Nepal and South East Asia, relatively small contextual shifts yielded forest turnarounds *by recruiting factors normally associated with deforestation*. Though the JFM agreements and agricultural intensification are clearly the causal or 'active' factors of reforestation, populous villages and a predominance of small-scale sedentary agriculture appear to be key, facilitative, *bi-functional* conditions without which the causal factors could not have operated. As I demonstrate, this 'recruitment' of the conditions of deforestation by nascent pathways of reforestation explains much of the expansion of forest cover in Panama's Bayano-Darién frontier.

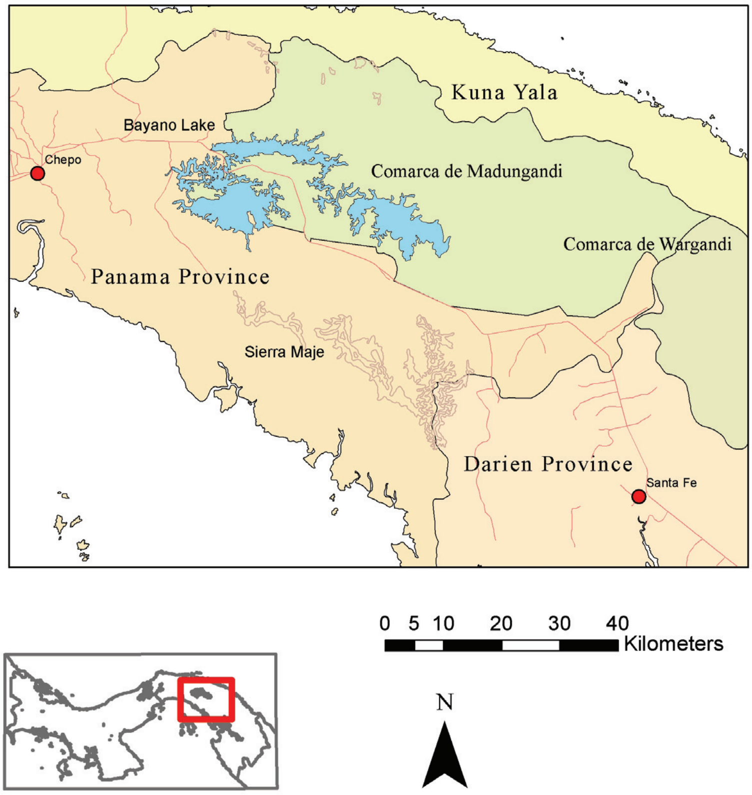
3.0 The Bayano-Darién Region: Simultaneity And Succession Between Pathways

The Bayano-Darién region compasses the area from Bayano Lake to the town of Santa Fe, Darien, and from the Sierra Majé mountains to and the Comarca Kuna de Madungandi indigenous forest reserve (Figure 1). Tropical lowland moist forest characterizes its ecology, with elevations between 50 and 900 meters, annual rainfall between 1600 and 2400 mm and an eight-month rainy season between May and December (Wali, 1989). As recently as the 1960s the region's predominant land cover was a contiguous, unsettled expanse of three-tiered tropical forest stretching from Chepo town to Columbia (Wali, 1989). Kuna and, more recently, Emberá Ameridians (Herlihy, 1987) reside in the region, collectively numbering a few thousand[9]. The Kuna remain physically and culturally distant from other populations and rely predominantly on extensively-planted tree crops and swidden agriculture (Wali, 1989), whereas the Emberá practice traditional agriculture as well as cattle rasing in cash cropping, similar to neighbouring *colonos* (Potvin et al., in press; Tschakert et al., 2007).

Colonos came and continue to come to the Bayano almost exclusively from the interior Los Santos province of Panama's Azuero Peninsula. Settlement began in the early 1960s, though in relatively small numbers and largely confined to the Chepo-

9 In the early 1970s the government estimated Kuna and Emberá populations at 1500 and 350, respectively, for the Bayano watershed (Wali, 1989: 38). Their respective populations were again estimated at 1313 and 324 in 1977-1978 (IRHE, 1978) and at 1500 and 820, respectively, in 1980 (Herrera, 1986).

Figure 1 – The Bayano-Darién Region, Panama.



Source: Author

Cañitas corridor west of Bayano Lake (Heckadon Moreno, 1981; McKay, 1976; McKay, 1984; Wali, 1989). The *colonos* proceeded to convert forest to pasture with such fervor that Wali (1989) reports that even those without cattle established pasture in hopes of leasing it to others. Over the 1960s, the *colono* population increased nearly 150 percent (Herrera, 1986), and by 1970 colonos numbered 4000 in the greater region (IRHE 1978; Wali, 1989). Between 1973 and 1975 the Bayano Hydroelectric Project relocated 2000 *colonos* from the fertile alluvial soils along the regions' rivers to the far western Chepo-Cañitas corridor as the lowlands were flooded (IRHE 1978; Wali, 1989). By 1976 the Bayano Lake was formed, the highway extended to the lake's western shore, reaching beyond to the Darién frontier by 1979, and the increasingly accessible but poorer soils surrounding the lake and bordering the highway were recolonized with renewed rapidity. Between 1970 and 1980 the *colono* population increased by 42 percent despite the relocation (Herrera, 1986). In point of fact, Herrera (1986) notes for five eastern localities[10] in the Bayano – four of which were sampled for the present study[11] – that the *colono* population increased by *300 percent* between 1977 and 1980, from 784 to 2318.

Despite earlier population increases, between 1990 and 2000 the total population declined (Figure 2). Simultaneously, the area in pasture and the number of cattle increased rapidly, producing an increasingly extensive and cleared but decreasingly occupied landscape typical of the hollow frontier (Figure 3; also see Section 5.2). Indeed, Figure 2 illustrates that the declines in the proportion of economically active residents practicing agriculture concentrated in villages loosing population and even declined when population increased, suggesting that agriculturalists first and foremost were those that left during the 1990s.

New dynamics that favour forest transition have recently begun to arise in the region. Residents and government officials alike have become increasingly conscious of the role of deforestation in seasonal droughts and water shortages, and residents have organized locally to moderate deforestation and promote afforestation in vulnerable water recharge areas. Additionally Simmons (1997: 992, 997) observes in the late 1990s that "unlike many frontier regions, livestock activities were not important to household livelihoods", continuing that "although (cattle's importance) may have been the case when the Bayano was first colonized, currently only 1 percent (of respondents) indicated ranching as a primary activity and such income only represents 6 percent of total income". Among *colonos*, wage labour constituted the most important economic activity by income, followed by logging and agriculture[12] (Simmons, 1997: 992). Finally, Law 24 of 1992 has stimulated the establishment of large timber plantations over pastureland in the region. Expansion has proceeded rapidly, with some years witnessing over 1000 ha of land acquired and planted in the greater Bayano region. The area reforested belongs almost exclusively to large national and international timber interests orientated towards overseas markets. In terms of the growing influence of foreign enterprises on LUCC (Rudel, 2007), the Bayano-Darién reflects modern trends in FCC. Foreign-enterprise driven FCC often effects forest extent negatively, however, and the case of the Bayano-Darién presents a rare example of the contrary.

[10] The five localities are: Tortí, Playa Chuzo, Higueronal, Río Seco – Wuacuco, and Cañazas.

[11] Being Tortí, Playa Chuzo, Higueronal, and Río Seco – Wuacuco.

[12] Simmons' (1997) figures must be considered with some caution. In such a context, determining the relative importance of such economic activities by income can be problematic. Activities such as agriculture are practiced primarily to provide sustenance, while pastoral activities provide economic security as well as cash income. Wage labour, in contrast, is undertaken to increase household income for consumption and investment. Nonetheless, given its economic rationale, it is telling that Simmon ranks pastorlism thusly.

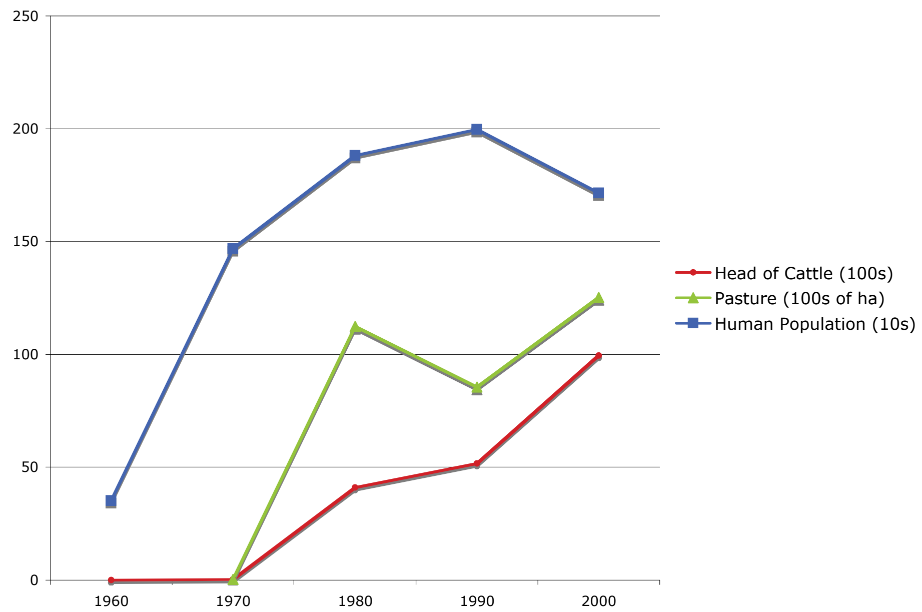
Figure 2 – Demographic Changes in Thirty *Colono* Communities of the Bayano-Darien Region, 1990-2000.

Source: (Controlaria, 1991: Cuadro 4, p. 444-446; Controlaria, 2001: Cuadro 3, p. 398-402)

Note: Each pair of columns represents a single community. The *colono* communities of Tortí (Tortí proper, Tortí Abajo and Tortí Arriba) are excluded on the grounds that most of their inhabitants do not participate in agriculture but rather are employed in the service sector, in which rapid localized expansion has produced rapid population growth of approximately 480 people over 1990-2000

In light of these events, this paper explores two possibilities for simultaneity and succession between the hollow frontier and the forest transition. At the household scale, emigration and off-farm employment by one or more adult member may diminish a household's on-farm activity. First, as the household dedicates resources elsewhere, regrowth or planting may occur on marginal and / or neglected lands as extended-period fallows, perennial stands, timber plantations or other labour-extensive land-covers. Simultaneously, the labour-extensive nature of cattle ranching, combined with the associated weight of familiarity and promise of quicker economic returns, may see such households promote pasture within their portfolio. Where these two outcomes coincide, so do the conditions, drivers and features of the hollow frontier and the forest transition.

Figure 3 –Land Use and Population in the Southern Bayano Region, 1960-2000.



Source: Adapted from (Dagang et al., 2003)

Second, at the landscape scale, the trend for large, corporate, 'successive' timber plantations to consolidate landholdings in the Bayano-Darién and transform them into particularly extensive properties mimes the manner with which ranchers succeed smallholders and 'hollowed' the frontier.

4.0 Methods And Data Sources

The patterns and causes of forest-cover change may vary according to the different scales of observation, as different drivers, agents and processes of change predominate (Geist and Lambin, 2002). Consequently, accounts of FCC are most compelling when observations made at one scale nest within, contextualize and triangulate with those made at another scale (e.g., Turner, 1999). This study therefore employs a multi-scale, multi-agent approach to FCC consisting of landscape-scale cartographic analysis and household-scale regression analysis.

4.1 Landscape-Scale Remote Sensing and Cartographic Analysis

Land-use/cover maps for the Bayano-Darién for 1990 and 2000 were created to assess land-cover change over the 1990s. Also, figures on the annual expansion of timber plantations area in the Bayano-Darién and the Republic as a whole were complied and compared over the period 1994-2004 to assess the prevalence of plantations in the Bayano-Darién frontier. These two steps required satellite, cartographic, photographic and land-registry data, all of which detailed below.

4.1.1 Land-Use/Cover Map and Aerial Photography for 2000

Remote-sensing practitioners concerned with the human dimensions of land-cover change have increasingly sought to go beyond purely vegetation / ecological land-cover typologies (e.g., Walker et al., 2000 for an example of the later) and to define culturally or socio-economically meaningful land covers, such as palm agroforestry relative to natural palm groves, or forest fallows of varying utilities to local households (Geohegan et al., 1998; Moran et al., 1994; Moran and Brondizio, 1998). Such practice, sensitive to *how* local populations *use* landscapes, requires extensive fieldwork during which the analyst, with the cooperation of locals, visits numerous sites exemplary of nuanced land-uses, catalogues their properties and manually demarcates their geographic coordinates for later input into the Geographical Information System (GIS) to 'train' the conversion multi-spectral satellite imagery into maps (Moran and Brondizio, 1998). With the analyst actively searching for and *defining* the land covers to map, cartographic outputs suggest not only the variety, local utility and social processes underlying anthropogenic forest covers, but hints at their persistence as well. Such an approach to remote sensing has been instrumental in redefining rural populations' perceived role relative to forest cover, from one of antagonist to one in which cohabitation or even positive synergies are possible.

The year-2000 map of the Bayano-Darién was created from Landsat ETM+ satellite imagery taken at end of the dry season (March). On-farm interviews served to inventory and demarcate land covers. Of the land covers requiring definition, 'forest' refers to three-tiered, climax closed canopy or mature secondary growth dominated by *cuipo* trees (*Cavanillesia Platanifolia)*; 'fallow/regrowth' to woody pioneer vegetation between approximately five and 15 years old, with sometimes sparse and highly spatially-variable canopy closure; 'plantation' to monotypic stands of teak (*Tectona grandis*) planted in a 3m-by-3m grid and aged between one and 17 years; and 'pasture' to any grazed or grassy land, hosting at most sparse scrub or palm trees. The relative simplicity of this categorization follows from local *colonos'* relatively limited land uses. Unlike other *colono* populations (Hecht et al., 1988), those of the Bayano-Darién rarely manage or keep tree crops, apart from the occasional few plantains.

'Training sites'[13] were delimited manually with a GPS and by means of 1:5000 aerial photographs[14] with the aid of false-colour composite images. The whole of the area in plantation was manually demarcated from the aerial photos, as adequate spectral separation of 'plantation' from 'pasture' proved impossible given the dry and defoliate conditions. Training sites for each land-cover class consisted of between 1300 and 3800 pixels, or 105 ha and 307 ha, respectively, areas sufficiently extensive to ensure maximal reliability adequate spectral separation between classes. Spectral separation was very high – the transformed divergence statistic (Richards, 1993: 245-53), a measure of spectral separation having an upper bound of 2000 and rule-of-thumb lower limit of 1600, measured 1995-2000 for the 4-spectral-band combination ETM+ 1 4 5 7. Distinctiveness was corroborated via graphical examination of classes' spectral signature over all bands.

Training site data were inputted into a maximum-likelihood classification algorithm for bands ETM+ 1 4 5 7. *A priori* probabilities defining the likelihood of a given pixel belonging to a given class were manually defined to correct for misclassification between similar land-covers of disparate areas (e.g., forest and fallow). A *priori* probabilities were defined by measuring the proportion of pixels having Normalized Differential Vegetation Index (NDVI) values associated with water, forest and unforested lands and iteratively assigning these proportions to land covers. Of the unforested lands, Adams et al.'s (2001) estimation that 80-90 percent of these lands were historically cleared for pasture served to define pasture's *a priori* probability, the remaining proportion of unforested land being allocated between remaining unforested land-cover classes.

The resulting year-2000 map presents a highly detailed and accurate illustration of the Bayano-Darién. Eight-five percent of pixels were correctly classified (n=136 random ground-truth points) an appreciable score but restrained by occasional misclassification of pasture as agriculture due to the extreme dryness of pasture. Upon merging 'pasture' and 'agriculture' classes into a single 'agro-pastoral' class, however, overall accuracy rose

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[13] 'Training sites' are geographically defined areas that are exemplary of the distinct spectral signature of each land cover and thus serve to 'train' the GIS when classifying satellite imagery into a land-cover map on the basis of spectral signatures.
[14] Photographs provided by *El Programa de Desarrollo Sostenible del Darién,* of the Government of Panama.

to 90 percent, with remaining error owing to the limits of the spatial resolution of the Landsat imagery in such a fragmented and variable landscape.

4.1.2 National Forest-Plantation Registry

The Reforestation Incentives Law 24 of 1992 stipulates that all plantations operations must inscribe in a national forest registry[15]. This registry lists for 1568 plantations established between 1992 and December 2004 data on proprietors, area reforested, year of reforestation, and location. Though the registry does distinguish between private and corporate owners, it lists only the area reforested at the time of registration and not the total area of the landholding. In almost all cases these areas are equivalent but, particularly for corporate-owned plantations, there is the possibility of phased expansion subsequent to registration, and it is uncertain how or whether such expansions would appear in the registry. Further, the year of reforestation as recorded in the registry may not always accord with a plantation's year of inscription. Large plantations registered in a given year may contain stands planted in that year as well as others planted in preceding year(s). Also, proprietors may simply belatedly register their plantation after establishment; this is, however, unlikely, especially for corporate-owned plantations seeking tax exonerations. Finally, as per a clause in Law 24 that offers Panamanian residency to foreigners upon a $40,000 investment in reforestation, Chinese nationals have established (with the cooperation of Panamanian plantation investment property companies, or *reforestadoras*) a large number of plantations as one-hectare stands. In 1995 and 1998, the years in which most such 'visa plantations' were established, visa plantations represented 43 and 54 percent of all plantations established nationwide, respectively, though they constituted a far less significant proportion of the area reforested in the same years. While these visa plantations are by no means anomalies or outliers, they do represent a special kind of plantation strictly limited in area. Average-area calculations are therefore performed both with and without their inclusion. In sum, though data simplifications potentially exist within the registry, they are infrequent and minor, particularly in view of the large number of inscriptions, such that the registry remains a valid and useful window into widespread reforestation trends.

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[15] The forest registry is managed by *El Servicio Nacional de Desarrollo y Administración Forestal, Autoridad Nacional del Ambiente* (ANAM). An Excel spread sheet of the registry can be obtained from the author.

4.1.3 Land-Use/Cover Map for 1990

Land-cover data for 1990 is based on the nationwide GIS coverage provided by ANAM (2003). Like the year-2000 land-cover map, that for 1990 was derived from Landsat satellite imagery, though for the early wet season (June). The land-cover classes mapped by ANAM (2003) generally agree with those mapped for 2000, though with certain exceptions. The 'regrowth' class in the 1990 map represents areas of pioneer tree species less than five years of age. An 'intervened forest' class represents mixed standing forest altered by human activity, and as such may represent areas older than 'regrowth' but which have not yet matured into secondary forest. Together, these classes approximate the regrowth class in the year-2000 map. The year-1990 map does not distinguish between agricultural and pastoral regions, but describes them collectively as 'agro-pastoral'. The 1990 map does delimit areas of 'subsistence agriculture', which include riverside (Amerindian) cultivation, fallow lands and farms penetrating forests. ANAM (2003) describes the 1990 map as 'highly precise', and though the categorical map was verified with field visits ANAM (2003) does not disclose a quantitative measure of classification accuracy. A visual inspection of Figure 4 suggests that while the map is accurate, it may underestimate the agro-pastoral area and simplified the boundaries between agro-pastoral and forest classes.

4.2. Household- scale logistic regression on deforestation and reforestation events

Through interviews with *colonos* I reconstructed households' LUCC histories, spanning on average 11 years (Table 1). Researchers have recently begun to reconstruct household land-use histories retrospectively, starting from the present time and working backwards by relying on seasonal, rotational or otherwise cyclic land-use or crop-fallow 'scripts' to aid respondents' recall (e.g., Abizaid and Coomes, 2004; Coomes and Burt, 1997). Such an approach, however, is ill-suited to the Bayano-Darién frontier, where *colonos* "process" land in a linear manner from an 'input' state (forest or fallow) to 'intermediate' states (short-term crops and sometimes fallow) to 'terminal' states (pasture) and may drastically reshape or erase the boundaries of land uses with each conversion. To account for this, I reconstructed land-use histories starting from the year the respondent acquired land and worked *forward* to the present. To aid respondents' recall I employed a system of cards representing *colonos'* land uses (forest, fallow, annual crops and pasture) and the

Table 1 – Summary Statistics of *Colono* Households in The Bayano-Darién.

	Mean	*Standard Deviation*	*Range*
Age of Household Head, Years, 2000	42.4	10.0	23-65
Number of Household Members, 2000	4.0	1.6	1-8
Labourers 15-64 Years Old, 2000	2.4	1.0	1-5
Years of Residence, Until 2006	19.1	6.7	7-29
Years of Land-Use History Collected	11.3	3.7	7-25
Number of Cattle Owned			
2001	19.42	41.2	0-200
2005	25.9	50.0	0-250
Number of Cattle Owned, Ranchers Only			
2001	42.7	51.7	3-200
2005	42.7	58.7	2-250
Landholding, ha.			
2000	47.1	64.5	1-295
2006	54.9	105.2	1-578
Landholding, Ranchers Only, ha.			
2000	81.9	83.1	1.5-295
2006	79.0	123.3	5-578
Deforestation, Virgin Forest Only, ha/yr., 2000-2006	0.48	0.95	0-4.2
Pasture Area, ha			
2000	24.73	44.0	0-194
2006	32.3	57.1	0-250
Pasture Area, Owners of Pasture Only, ha.			
2000	48.0	51.8	2-194
2006	51.9	63.3	2-250
Regrowth Area, ha			
2000	5.5	7.9	0-28
2006	4.2	7.3	0-24
Regrowth Area, Owners of Regrowth Only, ha			
2000	10.7	8.2	1-28
2006	10.8	8.1	0.5-24
Forest Area, ha			
2000	14.5	30.4	0-160
2006	16.1	52.9	0-300
Forest Area, Owners of Forest Only, ha			
2000	28.1	37.3	1-160
2006	33.2	73.1	1-300
Total Area Incorporated by Sample, ha			

2000	2590
2006	3016
N	55

Source: Communities included in survey are Wacuco – Rio Seco, Tortí (Tortí Abajo, Tortí Medio and Tortí Arriba), Playa Chuzo, and Higueronal

numbers of hectares assigned to each, with respondents allocating and re-allocating the later among the former as land was 'processed' from one use to another year by year. In many instances this accounting system easily facilitated the collection of over twenty years of data, year by year, hectare by hectare, and land use by land use[16].

This approach possesses several advantages over the retrospective strategy. Since it is congruent with *colonos'* linear, processes-orientated manner by which *colonos* use their land, it greatly simplified their recall and tracking of complex land conversions. In general, respondents had only to remember the area and the origin (usually forest or fallow) of land cultivated each year and what became of that land in the subsequent year (e.g., converted to pasture or to fallow). *Colonos* could easily meet this challenge. Land-use histories therefore retained a rich detail and high level of accuracy. To verify accuracy for recent land use/cover data, I measured the area pasture, crops or fallow in 2006 for a subset of respondents using a GPS and/or respondents' land titles documents, and compared these areas to those areas obtained from interviews (Table 2). Comparisons were favourable, with discrepancies being modest and balanced between over- and under-estimation. The lesser correspondence between *colonos* self-reported deforestation and satellite-based verification in Walker et al. (2000: 689) also testifies to the trustworthiness of this accounting system.

Interviews also furnished socio-economic data to analyze household reforestation and deforestation trends. Household reforestation events were defined as either an increase in fallow / regrowth or a decrease in pasture and/or agriculture area by ≥2 ha between 2000 and 2006. This broad definition captures the dynamism of the forest-turnaround point better than more static definitions of reforestation as the presence or absence of secondary forest (e.g., Rudel et al., 2002; Rudel et al., 2000). Deforestation 'events' are similarly defined as the loss of forest or fallow / regrowth or the expansion or pasture and/or agriculture by ≥ 5 ha over the same period. Variables were entered

Table 2 – Absolute and Percentage Discrepancies between Self-Reported and Measured Areas, in Hectares.

	Pasture n=6	Agriculture n=5	Fallow/Regrowth n=4	Overall n=15
Mean Discrepancy (ha)	2.1	0.5	0.9	1.2
Standard Deviation	0.9	0.7	1.1	1.0
Percentage Discrepancy (a)	4%	9%	8%	3%

Notes: (a) Calculated as mean discrepancy as a proportion of the mean area of land cover in subset of sample. Calculations for 'Overall' do not include forest cover area of landholdings.

into separate logistic-regression models explaining household reforestation or deforestation.

5.0 Results

5.1 Household Patterns of Forest-Cover Change

Table 3 presents a logistic regression model of household deforestation events in the Bayano-Darién. The model captures the typical dynamic of deforestation whereby households with greater *a priori* resources such as labour and land are more able to convert forest to other land uses. For instance, the addition of every mature household worker increases the odds of household deforestation by *1145* percent, and larger landholdings, containing more forest than smaller landholders (two-tailed $r=0.75$, $p<0.001$), increase the odds of deforestation by 21 percent for every additional hectare of landholding (cf. McCracken et al., 1999a: 1318)[17].

Unexpectedly, the odds of household deforestation *decreases* (by 15%) with each additional head of cattle owned by the household, whereas cattle is typically observed as both a motive of and a resource for further forest conversion (cf. McCracken et al., 1999a: 1318). Indeed, the correlation between the number of cattle owned and

[16] Forest, fallow, pasture and crops represent the entirety of colonos' land uses in the region. Perennial crops were so rare and limited in extent amongst colonos as to justify their exclusion. 'Kitchen gardens' were not observed.

[17] Given the strong correlation between the total size landholdings in 2000 and the area of forest within the landholding, the later could substitute for the former in the deforestation model of Table 4. Though the statistical significance attributed to total landholding variable transfers to the forest area variable, this substitution causes the variable representing the number of cattle owned by the household in 2001 to drop out of the model. In order to retain this important variable, and because deforestation events are predicted slightly better when total landholding rather than forest area is considered, the logit deforestation model om Table 4 is retained.

Table 3 – Logistic Regression Models of Household Deforestation and Reforestation

Variable[i]	Deforestation ≥ 5ha, 2000-2006	Reforestation ≥ 2ha, 2000-2006
Intercept	-0.75 (0.47)	0.68 (1.97)
Age Household Head, 2000	-.27* (0.13)	-0.14° (0.87)
Number of Cattle, 2001	-0.16* (0.85)	0.00 (1.0)[ii]
Landholding in Ha, 2000	0.19* (1.21)	
Number Household Workers, 2000	2.52* (12.45)	
Use of *Media*, 2000-2006 (yes/no)		2.62° (13.81)
Percent Landholding in Forest, 2000		0.07** (1.07)
% Overall Cases Correctly Predicted	80	90
Deforestation Only	80	-
Reforestation Only	-	70
Psuedo R^2		
Cox and Snell	0.56	0.36
Nagelkerke	0.75	0.59
N	55 households	

Notes: (i) Household workers are between 16-65 years of age. (ii) Unbracketed coefficients indicate the variables' additive effects on the logged odds of deforestation or reforestation e.g., an increase or decrease of one household worker increases the logged odds of deforestation by 2.52. The bracketed coefficients represent variables' multiplicative effects on the odds of deforestation or reforestation, e.g., an increase or decrease of one household worker increases the odds of deforestation by 12.45 times, or by (12.45 – 1) x 100 = 1145 percent. (iii) The exclusion of the variable 'Number of Cattle, 2001' from the reforestation model has no effect on the model.

** $p<0.01$, * $p<0.05$, ° $p<0.09$

household forest area is positive (one-tailed r=0.40, $p<0.01$; see also Tschakert et al. (2007) for the Bayano region). Similarly, whereas the household life-cycle theory expects advancing household age to associate firstly with deforestation, as households utilize increasingly labour resources to convert forests into land-based investments such as pasture, and to associate subsequently with reforestation as the landholdings of matured households contract for want of labour (cf. McCracken et al., 1999a; Perz and Walker, 2002; Walker et al., 2000; Walker et al., 2002), the odds of deforestation and of reforestation both decrease precipitously with greater age and do not reflect the expected curvilinear relationship with forest-cover change.

These apparent anomalies are explained by the dynamics of forest conversion in the region. Greater forest area on landholdings of households with many cattle is partly explained by the fact that larger ranches contain forest fragments bordering rivers or on steeper slops, in contrast to peasants' smaller and more thoroughly deforested agricultural lands (cf. Pichón, 1997). Also, the largest ranchers have recently acquired extensive tracts of partially forested land in order to continue to expand their herds. Smallholder *colonos* quickly converted their initial forest areas to pasture and conserved such diminutive areas of forest when younger that now, in their later years, deforestation proceeds slowly, if at all, for want of forestland. On the basis of the age-cattle correlation (one-tailed $r=0.40$, $p<0.01$), one might expect that the reduced odds of reforestation with increased age results from an accumulation of cattle by the household and a progressive extensification of land use. Mature households might occupy the full extent of their rough pasture almost indefinitely as their children leave to begin their own families – and indeed, perhaps for this reason appreciable levels of household emigration and off-farm employment did not significantly predict reforestation, contrary to expectations.

Reforestation is most likely where households participate in the traditional land-sharing institution of the *media* (literally, 'the means') – the odds of reforestation amongst *media* participants were 1281 percent greater than among non-participants. Traditionally, *medias* served as means by which large ranchers accessed labour in the form of land-poor peasants (i.e., 'participants') who, in exchange for the right to temporarily cultivate an area of the former's land, converted it into pasture afterwards (Gudeman, 1978). Today, *medias* in the Bayano-Darién predominantly take the form of a land-rich household letting land to a land-poor household with excess labour, who cultivates the borrowed land for one or two years and divides the yields with the landowner[18]. This form of *media* resembles the traditional practice, though with notable distinctions. The cultivated land, being almost always in fallow beforehand, usually reverts to fallow anew after cultivation, the purpose of the *media* from the landowners' perspective being merely to acquire grain cheaply and to keep forest cover from establishing itself on his lands. Also, *media* participants are not necessarily the landless or land poor; in our sample these households hold a median of 24 ha, yet they typically lacked the forest or fallow needed to cultivate, in part because of the presence of pasture. Yet, in part due to participants' own areas in

[18] An alternative form of *media* in the region occurs when a household owning cattle but not pasture grazes its cattle in the pasture of another, with the value of the weight gained by cattle divided between the households upon its sale.

pasture, they may lack the forest or fallow land of their own under which to cultivate. Consequently, among those whom laboured within *media* arrangements, fallow land expanded by five hectares on average on their landholdings, though in cultivating another's fallow land by four hectares on average much of this gain was offset.

Finally, a higher proportion of forest cover on one's land correlated with the expansion regrowth and fallow lands. Landowners convert forest into productive land uses such as pasture, with regrowth or fallow being intermediate byproducts of this process. Thus, half of the cases of reforestation appear to be at the expense of mature forest. Looking at the data differently, of all households experiencing reforestation events, 60 percent of their landholding on average was under mature forest, as compared with 20 percent for households not experiencing reforestation, suggesting that many 'reforesting' households were still also deforesting. Unlike in the deforestation model, the number of cattle had no effect whatsoever on the odds of reforestation. This result conflicts with empirical observations made by Rudel (2005: 56) and Rudel et al. (2002) and suggests that, as argued below, the economic *rationales of* extensification, and not solely the extensiveness of land uses per se, explain much of the endurance of such land uses in the face of forces for reforestation.

In sum, the coincidence of *colonos*, accessible lands, cattle and time results in near-inevitable forest-to-pasture conversion in which other factors do not easily intervene. For instance, while households with at least one emigrant possessed far smaller landholdings and less cattle as well as pasture and fallow land than households without emigrants over the period 2000-2006 (two-tailed t-test $p<0.01$ in all cases), there was no distinction between these groups in terms of pasture-expansion rates, deforestation rates or landholding-expansion rates; nor was there distinction in average incomes (Table 4). Further, in comparing households with and without off-farm income, the former were observed to have much higher average incomes (two-tailed t-test $p<0.01$) and to expand their pasture less rapidly on average than the later (two-tailed t-test $p<0.05$), but only *slightly* less rapidly (difference of means=0.75 ha/yr, means are statistically different by <0.25 ha/yr at present sample sizes); and again, there was no distinction in deforestation rates between the two groups (Table 5). Forest-cover change in any direction subsides as households mature *and* more completely 'process' their lands into pasture, indicating pasture to be an enduring feature of the *colono* landholding. The land-use/cover dynamic appears not merely as one in which the extensiveness of land use impedes reforestation by reducing the significance of, for instance, partial household emigration or off-farm

Table 4 – T-Tests on Household Income (2005), Landholding Size (2006), Cattle Herd Size (2005), Pasture Area (2006), Fallow Area (2006), and Rates of Pasture Expansion, Deforestation and Landholding Expansion (2000-2006), As Determined By The Emigration of At Least One Adult Household Member (1999-2003).

	Emigration		T-Value	Significance[i]
	Yes	*No*		
Income ($ / month)	250	303	0.398	0.64
Landholding (ha)	9.7	36.8	3.65	0.001
Herd Size (head)	1	20	3.18	0.004
Pasture (ha)	2.8	23.3	3.17	0.004
Pasture Expansion (ha / yr)	0.23	0.72	0.931	0.36
Conversion of mature forest (ha / yr)	0.5	0.45	0.87	0.93
Conversion of secondary forest (ha / yr)	0.05	0.31	0.505	0.61
Conversion of all forest (ha / yr)	0.55	0.77	0.342	0.73
Expansion of landholding (ha / yr)	0.45	0.08	0.533	0.59

Notes: (i) Statistical significance levels associate with a two-tailed test of the t-value in cases of equal and unequal variances.

Table 5 – T-Tests on Household Income (2005), Rate of Pasture Expansion (2000-2006), and Rates of Deforestation (2000-2006) As Determined By Off-Farm Income Held by At Least One Household Member[I] (2000), Bayano-Darién Frontier, Eastern Panama.

	Off-farm Income		T-Value	Significance[ii]
	Yes	*No*		
Income ($ / month)	481	177	2.87	0.007
Pasture Expansion (ha / yr)	0.18	0.93	2.23	0.03
Conversion of mature forest (ha / yr)	0.22	0.61	1.08	0.29
Conversion of secondary forest (ha / yr)	0.23	0.30	0.18	0.86
Conversion of all forest (ha / yr)	0.45	0.91	0.93	0.36

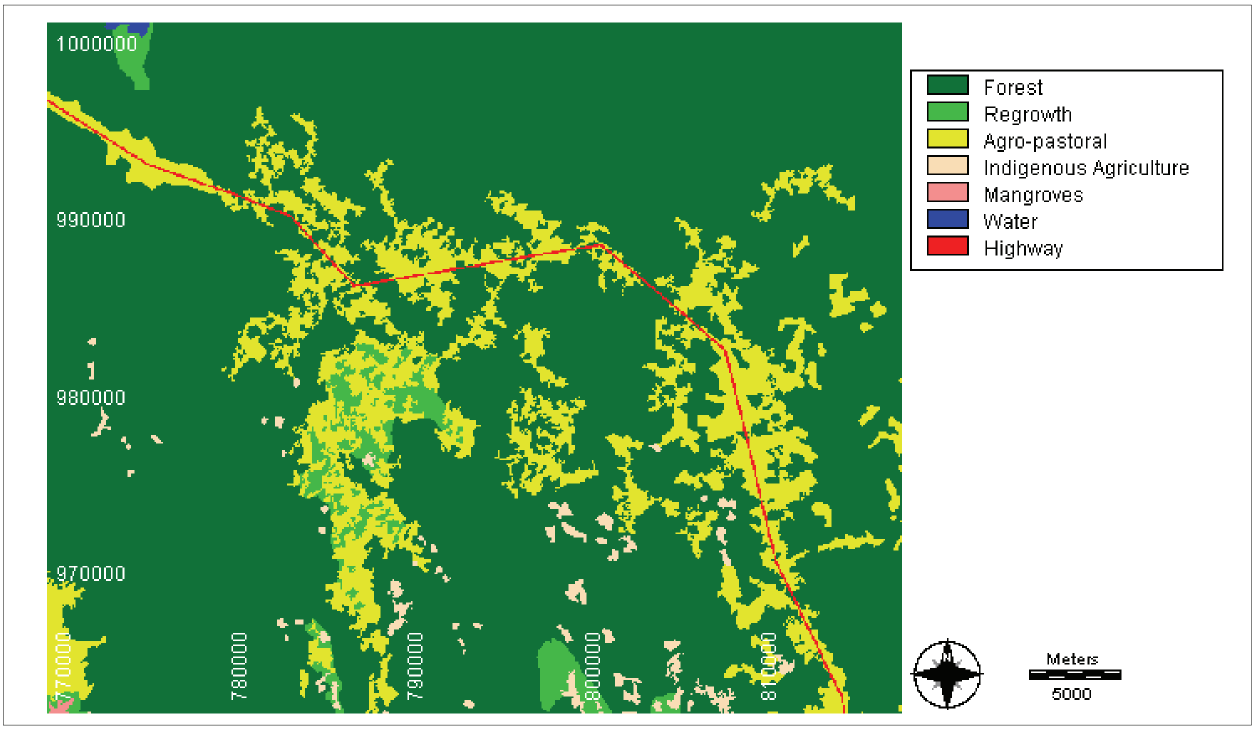
Notes: (i) Most households having off-farm income sources in 2000 maintained such income sources for years before and after 2000; (ii) Statistical significance levels associate with a two-tailed test of the t-value in cases of equal and unequal variances.

employment. Rather, *colono* households, in a context of relative forest abundance, poverty and labour scarcity, find any combined livelihood strategy involving further extensification more attractive than that involving little or none. This agrees with Vosti et al.'s (2003) observations that, even when provided with remunerative off-farm income, *colonos* still convert some forest to pasture in order to maximize their *overall* well-being, though they convert less than without off-farm income. It also agrees with Coomes et al.'s (in press) analysis of Bayano *colonos'* incentives for pasture expansion relative to direct payments for establishing timber plantations under The Kyoto Protocol's Clean Development Mechanism (CDM). They conclude that, given the economic rationality of pasture investment relative to timber plantations from *colonos*' perspective, the fate of the forest is cattle, not timber. Still, a great deal of afforestation has occurred over pastureland in the region. I examine this trend in the remainder of this section

5.2 Landscape-Scale Trends in Afforestation

Figure 4 through Figure 6 present land-cover maps of the Bayano-Darien for 1990 and 2000. Deforestation clearly expanded over the period 1990-2000 despite stagnating or declining populations (Figure 2, Figure 3). Pasture expansion was the chief cause of this deforestation (Figure 5). Simultaneously, however, timber plantations expanded significantly, accounting for at least 2500 ha by 2000 in the upper Bayano region alone. All of the plantation lands in 2000 were in pasture in 1990, indicating the great rapidity with which forest cover reclaimed denuded areas.

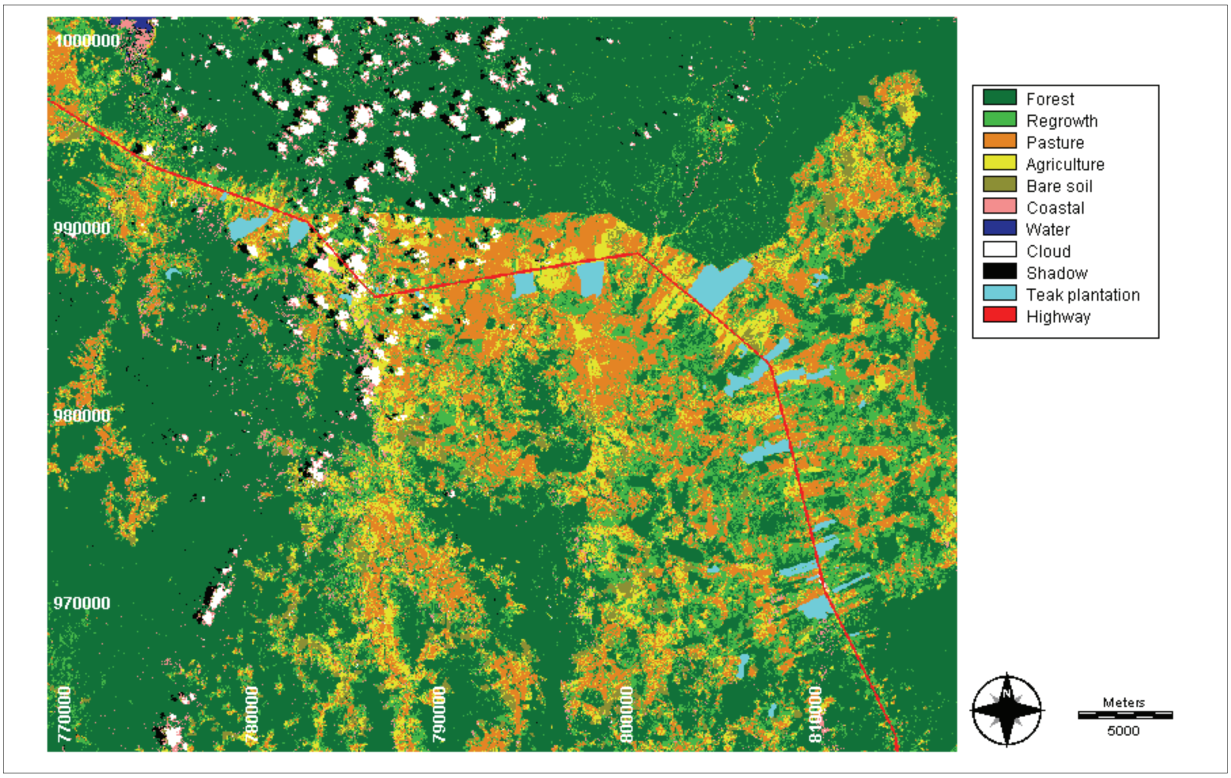
Figure 4 – Land Cover in The Bayano-Darién Region, 1990.



Source: Reclassification of Landsat satellite imagery. See ANAM (2003).

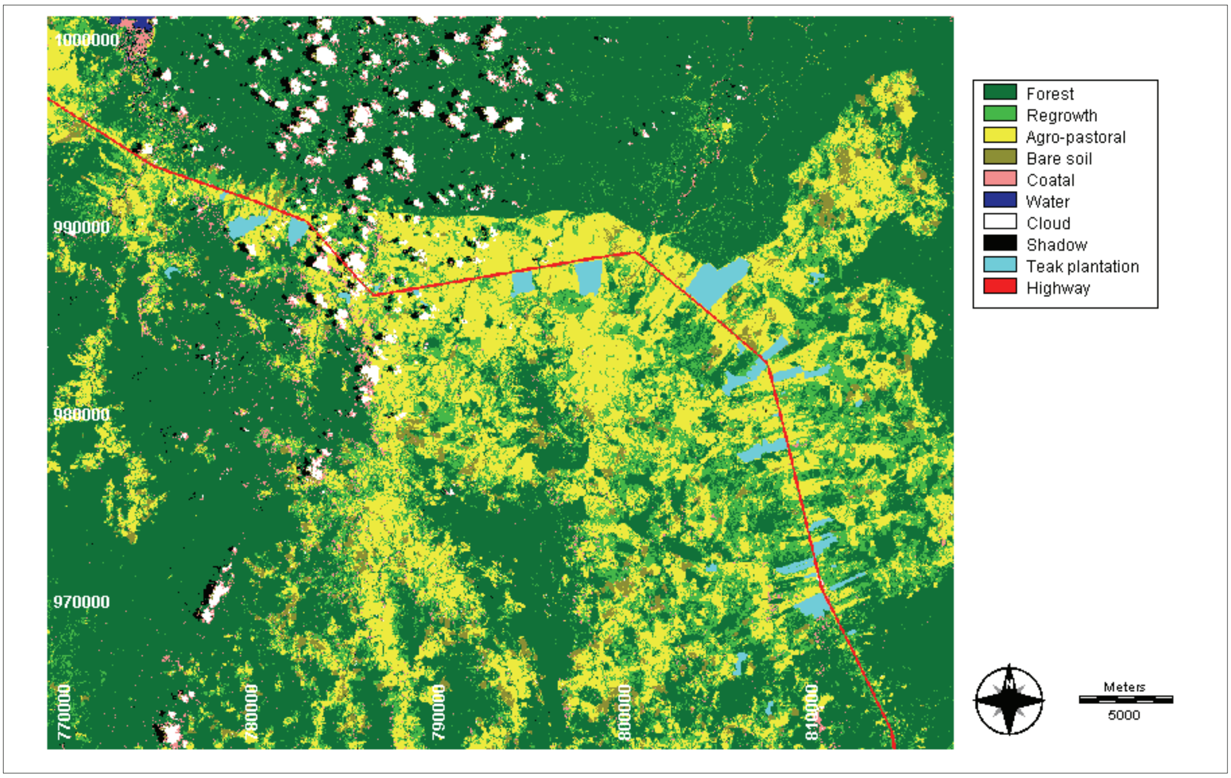
Note: The eastern-most edge of Bayano Lake appears in the top-left corner of the map. The highway appears as approximately 100 meters wide for visibility. Numbers in the margins are UTM coordinates.

Figure 5 – Land Cover in The Bayano-Darién Region, Pasture and Agriculture, 2000.



Source and Notes: See Figure 6

Figure 6 – Land Cover in the Bayano-Darién Region, Agro-Pastoral only, 2000.



Source: Reclassification of Landsat satellite imagery.

Note: The eastern-most edge of Bayano Lake appears in the top-left corner of the map. The highway appears as approximately 100 meters wide for visibility. Numbers in the margins are UTM coordinates.

The agents of plantation reforestation in the Bayano-Darién are distinctly non-local and well financed. Inscriptions in Panama's National Forest Registry for the Greater Bayano Region[19], in which every plantation owner must appear as per Law 24, were coded as to whether the landowner was (a) a national or international timber corporation, (b) a *reforestadora* (i.e., a relatively smaller commercial interest that establishes and sells young plantations as investment properties) or a non-forestry commercial interest (i.e., clients of the *reforestadoras,* such as insurance companies), or (c) an individual, local or otherwise. Due to probable errors in distinguishing forestry corporations from *reforestadoras*, these categories were also merged and coded as one. Table 6 compares the afforesttion activity of each group to the others, showing that of the 4860 ha afforested in the greater Bayano from 1992 to 2004, commercial interests afforested 4377 ha (90%) and 23 timber corporations alone afforested 3465 ha (71%). Further, the corporations established plantations on average eleven times greater than those of individuals while numbering nearly as many. Of the plantations owned by typically urban-based individuals, areas rarely exceed 20 ha and regularly less than 10 ha; yet of the plantations managed by international corporations, properties regularly exceed 100 hectares and the total scale of a single operation (i.e., planted lands, reserve land, marginal lands and planned expansions) may measure several hundred to over one-thousand hectares (Figure 7).

Plantation interests purchase land as pasture from *colonos* (Figure 8) and, as such, the plantation sector has been a force driving land consolidation in the region. As with earlier expansion of pasture, population displacement and localized depopulation can result from of plantation expansion. Differences in land use and profits between the plantation and peasant sectors explain much of this dynamic. For instance, land values have increased greatly over the 1990s to $3000 per hectare as a result of upward pressure by the plantation sector. *Colonos* cannot realize comparable incomes per hectare, particularly as most lack formal land titles and therefore cannot access investment credit. Nor can *colonos* establish even a modest plantation of their own, again due to the lack of land title and capital / credit but also due to prohibitively short discount rates (Coomes et al., in press), an inability to exploit the commerce/tax-orientated incentives of Law 24, insufficient managerial skill, and/or lack of sufficient land. *Colonos* therefore capitalize

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[19] Panama's national forest registry actually presents figures for Eastern Panama Province, being the area between the town of Pacora and the Darién provincial border in the east. Excluding the small area between Pacora and the town of Chepo, however, much of which is peri-urban sprawl, this definition perfectly circumscribes the greater Bayano frontier.

Table 6 – Distribution Of Plantation Area Between Corporate, Local Commercial And Individual Plantation Owners, Greater Bayano Region, 1992-2004, in Hectares.

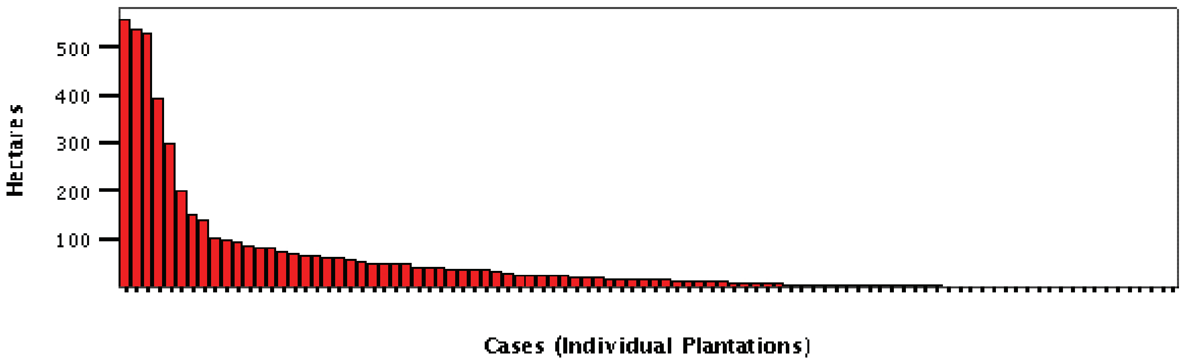
	Corporations	*Reforestadora* and non-forestry orientated domestic commercial interests	Individuals	Total
Mean	150.6	26	13.4	51.7
Total Area	3465	911	483	4860
Range	5--559	1-151	1-56	1-559
Std. Dev.	181	33	17.4	107
N	23	35	36	94

	Corporations, *reforestadoras* and non-forestry interests	Individuals	Total
Mean	75.4	13.4	51.7
Total Area	4377	483	4860
Range	1-559	1-56	1-559
Std. Dev.	130	17.4	107
N	58	36	94

Source: The National Forest Registry of The National Forest Service, ANAM, Government of Panama.

Notes: "Total Area" is a cumulative sum. The forest registry contains no inscriptions for forest plantations for 1992 or 1993, and does not extend past 2004. Plantations registered as 0ha were excluded.

Figure 7 – Area Distribution of Plantations Established Between 1992 and 2004, Greater Bayano Region, Eastern Panama.



Source: Author. Data from National Forestry Registry, ANAM, Republic of Panama

Notes: N = 94 plantations, Mean Area = 57 ha, Standard Deviation = 107 ha

Figure 8 – Teak Plantation (yellow crowns) Succeeding Pasture, Eastern Bayano, 2006.

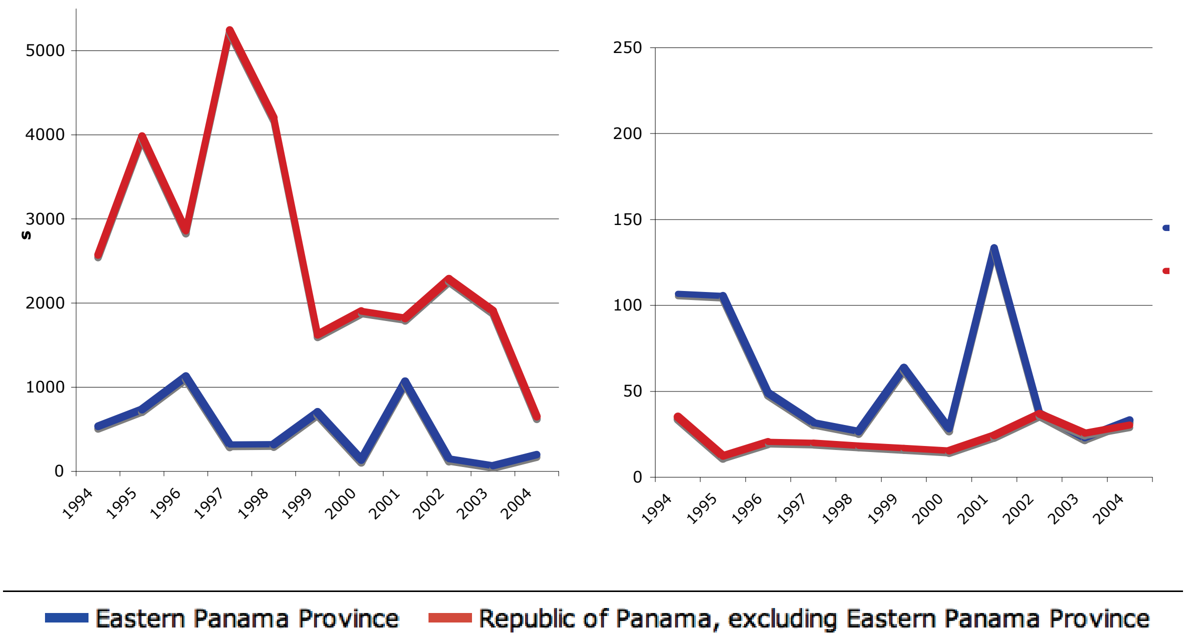
Source: Author's photo

on their land's value by selling pasture to the plantation sector, which can exploit the incentives and reap the long-term rewards to their fullest.

The rise of plantation reforestation in the Bayano-Darién thus exhibits the features of the hollow-frontier pathway of forest-cover change. As per a traditional hollow frontier, disparities between local incomes and *inflated land values* spurred locals to sell rather than retain their lands. This, in turn, encouraged *the emigration or displacement of colonos* as *large holders succeeded them* in the landscape, leading to extensive forest-cover change at the hands of a relative few large landholders. As with the traditional, pasture-orientated hollow frontier, particularly prominent in the Brazilian Amazon (Binswanger, 1991; Fearnside, 1997; Hecht, 1985), forest plantations in Eastern Panama also represent an *expansive, extensive, capital-intensive 'organizational' land use.* Indeed, Figure 9 illustrates that the reforestation-via-plantation expansion pathway was highly attracted to the hollow frontier: though Eastern Panama Province (i.e., The Greater Bayano Region) constitutes only a miniscule percentage of the national area of arable land, the region hosts a markedly disproportionate share of the area afforested nationally. Rates of land-cover change associated strongly with *subsidies* and macro-economic – rather than local – conditions that effect capital availability, to which large-scale interests are the most responsive and which indirectly can *inflate the size of landholdings* (Binswanger, 1991; Fearnside, 1997: 682). Figure 9, Figure 10 and Table 7 highlight *subsidies' role in inflating landholdings* in the hollow frontier by illustrating (1) that plantations in Eastern Panama Province were more extensive than for the nation as a whole and (2) that this was true only until 2002, the year subsidies and exemptions to the reforestation sector were

Figure 9 – Area of Annual Plantation Establishment for The Republic of Panama and Eastern Panama Province, 1994-2004, in Hectares.

Figure 10 – Average Annual Area of Plantation Establishment for The Republic of Panama and Eastern Panama Province, 1994-2004, in Hectares.



Source: Adapted from The National Forest Registry

N = 1304 (Panama) and 94 (Eastern Panama Province).

Notes: 'Eastern Panama Province' incorporates the area from Chepo town to the western Darién border, and as such defines the Greater Bayano Region of Figure 1. Averages do not consider plantations inscribed in the Forestry Registry having 0 hectares reforested at the time of registration.

curtailed, after which point there was little difference between afforestation in the hollow frontier and afforestation elsewhere. These subsidies gave rise to *inflated landholdings* and included varied *tax exemptions* on titled land and declarable income that only *commercial ventures* could fully exploit. Like in Brazilian hollow frontiers were pasture predominates, subsides inflated the price of land and *poorer landholders were excluded* from participating in the boom (Binswanger, 1991: 822). As such, plantations ascended in the landscape via *land consolidation*, and it was *exogenous, large-scale interests* capitalizing on the boom that caused much, if not most, of the land-cover change (Fearnside, 1997: 682). While the traditional hollow-frontier dynamic persists in Eastern Panama, the simultaneous and successive *corporate* frontier of plantation afforestation therein represents an exaggeration of the traditional dynamic. Extensive pasture is consolidated into even more extensive

Table 7 – Average Area of Plantations Established, in Hectares.

	`1992 to 2002	*1992 to 2004*	*2002 to 2004*
Nation less Eastern Panama Province			
All plantations	21.63 (sd.=70, n=1275, area=27,579)	21.97 (sd.=69, n=1372, area=30,155)	30.19 (sd.=59, n=161, area=4861)
Excluding 'visa plantations'	27.41 (sd.=78, n=995, area=27,274)	27.33 (sd.=76, n=1092, area 29,850)	30.19 (sd.=59, n=161, area=4861)

	1994 to 2002	*1994 to 2004*	*2002 to 2004*
Eastern Panama Province	54.01 (sd.=111, n=85, area=4591)	57.70 (sd.=107, n=94, area=4860)	32.07 (sd.=41, n=13, area=417)

Notes: 'Eastern Panama Province' incorporates the area from Chepo town to the western Darién border, and as such defines the Greater Bayano Region of Figure 1. All calculations exclude entries in the Forest Registry having 0 hectares reforested upon registration. S.d. = standard deviation. Area = total area of all plantations included in calculation.

plantations, successive ranchers are displaced by even more exogenous and well-financed interests, and the distance between local and ultimately-successive landholders widens as the hollow frontier is itself hollowed (see Chapter 2).

6.0 Discussion

Key observations of this study of the Bayano-Darién region of Panama are summarized as follows.

- Deforestation is explained principally by coincidence of household labour and forest cover. The non-exclusive nature of these resources suggests that deforestation is somewhat inevitable in the frontier.
- The 'middle-ground' between the forest transition and hollow-frontier dynamic, for which I hypothesized that extensive pasture and forest cover might simultaneously expand over landings, was not observed. *Colonos* expanded farms and ranches, but they seldom reforested and almost never afforested their land.

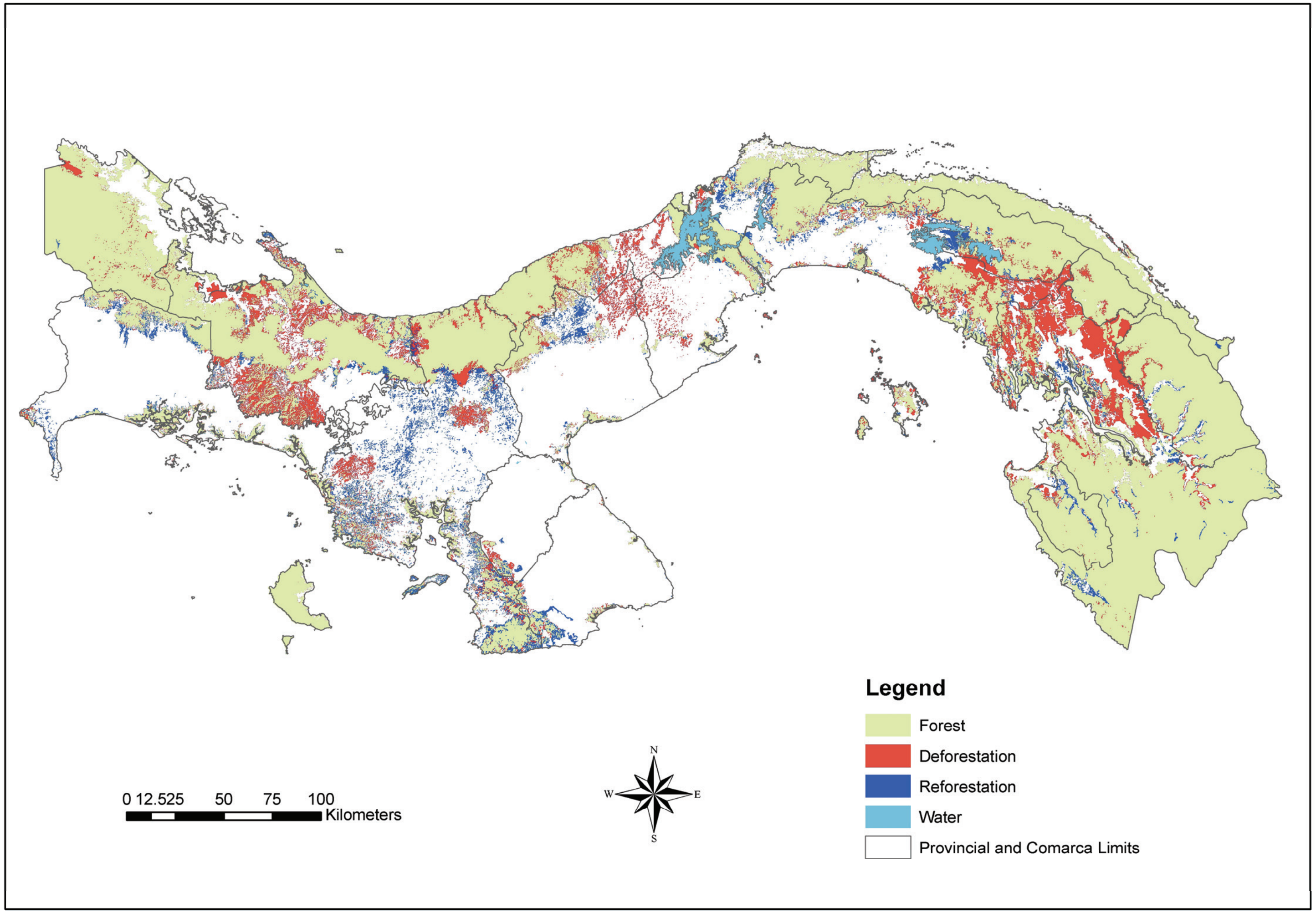
- Most reforestation occurred on small to medium-sized landholdings whose owners temporarily rested portions of their landholdings while participating in *medias* to access land elsewhere. This suggests that removing landowners from the land is the most direct path towards reforestation, as the forest-transition theory suggests.
- Foreign timber interests overwhelmingly led afforestation in the Bayano-Darién. Their ascent in the landscape as 'successive' landowners mirrored the archetypal ascent of successive ranchers in hollow frontiers and was driven by similar factors. The outcome is a progressively hollowing, yet reforesting, frontier that describes a pathway of reforestation which is successive, simultaneous and correspondent to the preceding hollow-frontier dynamic.

These observations, in turn, have implications for understanding forest-cover change in general and forest transitions in particular, across Latin America and beyond. The following sections conclude this chapter by discussing some of these implications.

6.1 A novel approach to the forest transition: simultaneity and succession amongst pathways

This study offers a novel examination of the forest transition by concentrating not on the presence or absence of secondary forest (e.g., Rudel et al., 2002; Rudel et al., 2000) but on a *forest-turnaround point* where reforestation emerges amidst deforestation at the regional scale. With some exceptions (Klooster, 2003; Perz and Skole, 2003; Rudel, 2005: 134-137; Rudel et al., 2002), many analyses of the forest transition lack the contextual resolution necessary to describe its LUCC dynamics. Instead, researchers have often preferred to explore the forest transition at the national scale (Ewers, 2006; Mather, 1992; Mather and Needle, 1998; Mather and Needle, 1999; Rudel, 1998; Rudel et al., 2005). Not only do such analyses lack spatial resolution and geographic bounds meaningful to *processes* of land-cover change, but their scale also precludes consideration of the role of land-use histories or pathways relative to the forest transition. For instance, Figure 11 clearly demonstrates that reforestation trends in Panama are particular to certain regions having particular and shared histories relevant to reforestation; yet an aggregate consideration would conclude on the basis of a slightly negative rate of national forest-cover change (-0.2% per annum, 1990-2000; FAO (2006)) a transition has not yet occurred. This oversight is not insignificant, for the emergence and nature of a forest transition *depends upon the preceding land-use dynamics* (Grainger, 1995),

Figure 11 –Forest-Cover Change in Panama, 1990-2000.



Source: Author. Data adapted from satellite-imagery analysis of ANAM (2003).
Note: Tree plantation not considered. Also, though ANAM (2003) claims to observe forest-cover change over 1992-2000, all but one satellite image of areas within Panama for the beginning of this period were for the years 1988-1990.

which are highly regionally specific and not equally facilitative of the transition. Similarly, research has neglected the social processes underlying reforesting landscapes – a critique from which local case studies are not immune. Thus, though previous research has highlighted key macro correlates of national reforestation events (e.g., GDP/capita), relatively little is known of the LUCC dynamic of forest-turnaround point, or how drivers of the transition operate at more local scales, or what trajectory the transition might take in regions having particular historical pathways of LUCC, such as the hollow frontier. In agreement with calls by the Science and Implementation Plan of the LUCC scientific community, (Lambin et al., 1999), the need for theoretically informed sub-national but generalizable case studies is paramount. This study has responded by examining the forest-turnaround point in a region of Eastern Panama.

The possibility of succession and simultaneity between the forest-transition and hollow-frontier pathway was examined at the landscape and household scale with particular reference to common, potentially bi-functional factors such as rural emigration. At the landscape scale both simultaneity and succession were observed as the 'contextual shift' represented by Law 24 coincided with features of the hollow frontier promoting plantation afforestation. At the household scale, however, the drivers of the forest transition failed to associate with reforestation owing to the persistent rational for forest conversion. The divergence of these outcomes at the landscape and household scales produces a disharmonious pathway of forest-cover change in which both household and landscape outcomes accord with the preceding hollow frontier but also diverge in their effect on forest cover.

6.2 Landscape scale: Might reforestation as a land-use counter deforestation as a land-use outcome?

This study observed forest-plantation expansion pathway to coincide with and succeed pasture. In this, it arguably presents an alternative to Grainger's (1995) thesis that the land-use transition is distinct from the forest-replenishment transition and that the former must end for the later to begin and usher in an enduring forest transition. Where reforestation itself results from land-*use* (i.e., afforestation), and not the absence of land use, there may be little distinction between these transitions. Indeed, this study demonstrates that, particularly where slight contextual shifts encourage a forest-turnaround point, the pathways and factors of reforestation and deforestation may be very similar, such that the former succeeds the later in the same manner as the later ascended in landscape in the first place. Instances of plantation and woodlot expansion in South Asia, described earlier, are consistent with this reasoning.

This chapter also demonstrates that appreciable reforestation is possible – even in colonization frontiers – when incentives are attractive. Indeed, that the manner of reforestation observed (market-driven plantation expansion) in the Bayano-Darién is seen typically in contexts of forest scarcity and high forest-product prices is telling. In this vein, there are grounds for cautious optimism. While teak monocultures substitute poorly for natural regeneration in ecological terms (Healey and Gara, 2003), their rapid ascent in the Bayano-Darién demonstrates that plantation reforestation does hold promise to counter deforestation, particularly where, as in the Bayano-Darién, it is amenable to preceding patterns of land-use/cover change. Indeed, in many cases plantation forests may be indispensable to the re-establishment of natural tropical forest cover and associated ecological services in degraded landscapes (Lugo, 1997). While plantation reforestation remains contentious, it possesses the unique advantage of inviting the participation of the private sector, which represents an advantage in poor tropical nations. It is plausible that reforestation incentives such as Panama's could be revised to encourage plantations for ecological services and forest succession while maintaining incentives to attract the private sector (Lamb et al., 2005).

Still, in Latin American forest frontiers, reforestation incentives such as Law 24 may be fatally limited in their ability to counter deforestation. Whereas large ranchers (> 100 ha) cause most forest destruction in the Brazilian Amazon (Nepstad et al., 1999), such that conservation efforts aimed at smallholders are futile (Fearnside, 1997: 682), small- and medium-sized landholders (i.e., approx. <15 ha and < 100 ha, respectively) still play the greatest role in forest-cover change in the Bayano-Darién and other neotropical forest frontiers. Despite the Panamanian reforestation boom lead by large corporations, the forest area that small- and medium-sized landholders converted to pasture exceed the area afforested by a significant extent. If reforestation is to gain ground over deforestation in such forest-abundant contexts *before* deforestation slows for want of forest, it seems imperative that smallholders also have incentive to afforest (Lamb et al., 2005). As observed here, however, government reforestation incentives in Panama overlook the peasantry. Further, providing peasants with reason to reforest/afforest calls for more than a mere tweaking of these incentives. Peasants are wholly different to commercial interests, and their motives, goals and capabilities are similarly unique. Distinct reforestation/afforestation incentives would have to be devised to incite and supplement peasants' livelihood strategies. This is not an easy feat given *colonos'* dependence on and economic rational for forest-to-pasture conversion (Coomes et al., in press; Vosti et al., 2003). Forest conversion will also have to be retarded if reforestation is to meaningfully recover landscapes (i.e., there is no gain made in afforesting an area equal to that cleared of mature forest). Given *colonos'* disincentive to allow reforestation or practice afforestation, gains in forest cover may be most easily won by economic means that encourage the contraction of pasture and/or the promotion of alternative land uses, such as subsidized sustainable forestry and direct payments for forest preservation (Arroyo-Mora et al., 2005; Berti, 1999; Coomes et al., in press; Sánchez-Azofeifa, 2000; Vosti et al., 2003). Just how to achieve this in the hollow frontier remains under-defined[20].

6.3. Household Scale: Emigration, Off-Farm Employment and Forest-Cover Change

At the household scale, this paper hypothesized that the decreased on-farm presence of a household owing to the emigration or off-farm employment might allow forests to recover on marginal agricultural lands while also promoting pasture holdings, due to its labour-extensive and profitable nature. Though a simultaneous expansion of forest cover and pasture sounds unlikely, Preston (1998: 155) observes as much in a context of cyclic wage migration for off-farm incomes in the southern Bolivian highlands:

> *For some people with ample land for cultivation and some capital, a suitable strategy is to cultivate only as much land as is needed to produce sufficient maize and potatoes for the year and to use other cultivable land for grazing. After a few years without being cropped, a dense growth of acacia (churqui) covers the fields which provide shade for better grass growth between the trees, improves the soil through the fixation of atmospheric nitrogen, and provides fuel wood for the household. One of the households studied during the period 1993-96 maintains a field which, a generation ago, was used for crops by their grandparents. The father and one or two of his elder sons works in Argentina for half the year and it is logical to minimize the area cultivated, which needs more labour, and to keep more cattle close to home.*

While suggestive, Preston's (1998) study does not address of the role of emigration and

[20] A precipitous decline in beef prices is one near-certain means of causing the contraction of pasture in forest frontiers (Arroyo-Mora et al. 2005; Sánchez-Azofeifa 2000). This avenue, however, may also mean a serious decline in the economic well-being of *colonos* (Vosti et al. 2003). Further, in frontiers characterized

wages relative to other household factors. The efficacy of such factors in promoting forestation in non-pastoral regions of Latin America appears somewhat assured, though with qualifications (Klooster, 2003; Rudel et al., 2000). Rudel et al. (2002) attempt to determine the *relative* effects of emigration and other household variables on reforestation amidst widespread pastoralism; yet, despite observing emigration, they do not observe reforestation[21]. While this itself constitutes a significant observation, corroborated by the present study, Rudel et al.'s study cannot inform us on the land-cover dynamic or the mechanisms of change where reforestation *does* occur in a hollow frontier. This chapter finds that emigration and off-farm employment had little bearing on reforestation and that, contrary to expectations, these factors *demoted* pasture holdings without significantly lessening deforestation. Again, contrary to expectation (see Rudel, 2005: 44-5), the extensiveness of land use in the region (as measured by the number of cattle owned) had little noticeable influence on the potential for reforestation. This may reflect the fact that little genuine reforestation occurred on household landholdings, but it also suggests that the value of forest conversion relative to land-use alternatives means that deforestation will continue without significant reforestation occurring.

Still another, complementary explanation exists for the lack of household reforestation despite emigration and off-farm employment. As noted, households experiencing emigration and off-farm employment held smaller landholdings and had limited involvement in ranching. Rural emigration and off-farm employment have long been observed amongst smallholders of Latin American without notice of reforestation. In the latter decades of the 20th Century a 'land squeeze' and resultant increase in labour surpluses in the peasant / smallholder sector (i.e., ≤ 10 ha) throughout Latin America prompted smallholders to migrate and seek wage labour (de Janvry et al., 1989: 406-18; Williams, 1986). By the 1970s, de Janvry et al. (1989: 410-11) estimated that wage labour provided approximately half of the total income of Latin American smallholders and very smallholders (i.e., ≤ 5 ha) in proximity to labour markets. In the early 1990s, the proportion of the economically active rural population engaged in non-agricultural activities rose across Latin America to average one-in-four (Orgega, 1992) and much higher in specific localities across the continent (e.g., Schweigert, 1993). Further, many rural households participating in the nonfarm and urban sector maintained agriculture as a secondary occupation (e.g., Klooster, 2003; Waters, 1997). As rural residents

by poverty, distance to markets, forest abundance and/or a lack of economic alternatives, such a trend may still not halt forest conversion (Rudel 2005: 46**).**

[21] Reforestation is observed only amongst the Shaur indigenous, who rely on pastoralism only minimally.

increasingly adopted 'urban' activities, agriculturalists increasingly adopted urban or peri-urban localities (de Janvry et al., 1989; Orgega, 1992); other still live in constant, iterant migration between village and city (Waters, 1997) or between village and agricultural plantation (Hamilton and Chinchilla, 1991; Schweigert, 1993). Smallholders' ready adoption of migration and wage labour has removed some of their labour surplus, yet it has not removed smallholders from their land (Kay, 2000). So long as smallholders remain a "cornered population" (de Janvry et al., 1989: 406), increasingly dependent on precarious, often-distant or seasonal off-farm income as a subsidy to their livelihoods but unable to wholly rely on such income and abandon their lands altogether, this scenario will likely persist alongside that of the more economically-secure ranchers. Despite the failure of large landholdings or cattle herds to significantly predict household reforestation events (or the lack thereof) in the Bayano-Darién, the parallels between smallholder labour surpluses owing to land squeezes and largeholder labour surpluses owing to extensive land uses supports the notion that land-use extensification runs counter to reforestation.

The failure of emigration and nonfarm income to precipitate reforestation in the Bayano-Darién raises points requiring more attention. At the household level, this study considered emigration as the departure of one or more mature household members regardless of permanency or motive. As well, it considered off-farm income gained from distant as well as local sources on a full-time as well as half-time basis. It is plausible, however, that in the Bayano-Darién, emigration and off-farm income must combine in a highly specific way in order to give rise to reforestation. Two studies which observe forest-cover resurgence driven by such factors in pastoral regions of Latin America both observe widespread, long-term and long-distance distant wage migration to well-paying destinations (the USA and to Argentina) by household heads and their sons (Hecht, 2004; Preston, 1998), which would seem to suggest such a 'specification'[22]. As argued, substantial rural emigration and off-farm activities may be required for reforestation to result in contexts defined partially by labour surpluses and extensive land uses. In their absence, changing economic rather than demographic factors may influence forest-cover change more greatly in such contexts – witness, for instance, the forestation resultant of the 'cattle crisis' in Costa Rica (Arroyo-Mora et al., 2005; Sánchez-Azofeifa, 2000) or the

[22] Rudel et al. (2000) similarly observe widespread reforestation of Puerto Rice upon the large-scale and long-term emigration of Puerto Rican coffee growers to the capital city of San Juan but also to the USA. Rudel et al. are unable to draw a definitive relationship between reforestation and emigration to the USA vs. San Juan, however.

economic rationales of ranchers to preserve subsequent secondary forests on their lands (Berti, 1999: 42-63). Finally, in forest-abundant contexts there is little reason to expect that increased / more remunerable off-farm income will necessarily result in farm contraction and reforestation per se. Rather, landholders may simply slow the rate at which they convert forest to pasture as they optimally combine diverse income sources with forest conversion. Further research should clarify the specification and the roles of emigration and off-farm income relative to reforestation and to more macro-economic forces in pastoral regions of Latin America.

Regional-scale accounts of tropical forest transitions must continue to qualify the temperate-nation origin and acontextuality (indeed, universality) of the forest-transition theory. A promising way forward is historical-comparative analyses (Perz, 2007), i.e., the cobbling together numerous analyses in order to examine reforestation trends over time for distinct regions. Rudel (2005) provides an excellent example for seven macro-regions of the global tropics. Such an approach allows for a 'two-way interaction between theory and data'. Future research should apply this approach to the sub-national scale and regional-scale pathways of LUCC therein, such a pastoral regions and the hollow frontier. Upon uncovering more fully the nature, drivers and extent of reforestation (or lack thereof) for a typology of regions and pathways of LUCC rather than for nations as a whole, and then considering the relative commonality or rarity of such regional contexts within and across nations, we can then 'scale up' our understanding of national or regional forest transitions without loosing the resolution or explanation inherent to lesser scales.

CONCLUSION

This thesis has made numerous observations concerning reforestation, deforestation and the forest transition in eastern Panama. On their own these are informative, but together they provide illuminating insights on the forest transitions more generally. The tropical forest-transition theory remains in an early stage of development relative to theory as applied to more temperate nations (Mather, 1992; Mather and Needle, 1998). More carefully-selected tropical case studies are needed to untangle and synthesize the daunting diversity of tropical forest-cover change if the theory is to solidify (Lambin et al., 1999). The special yet general context of the Bayano-Darién frontier, in which recent reforestation coincides with deforestation and where settlers, communities and commercial interests interact, serves as a particularly educational case study. Drawing from Chapters 1, 2, and 3, this section offers concluding reflections on tropical forest transitions.

This study has advocated the concept of pathways of land-use/cover change and attention to household resource-asset combinations as key to understanding forest transitions (Ch.3, Sec. 2.0). As agents of forest-cover change combine the environmental resources and household assets at their disposal, they formulate livelihood strategies or life-paths particular to their environmental conditions and which set in motion particular trajectories of forest-cover change. Subsequent generations inherit the environment conditions altered by their predecessors but also the household assets, livelihood strategies and sunk costs particular to their predecessors' trajectory of forest-cover change. Subsequent generations therefore continue the path of forest-cover change loosely set for them by their predecessors, but they do so under different terms, namely new environmental conditions but also the associated economic opportunities. Arguably, as these new terms accumulate, transitions from long-established pathways of deforestation to new pathways – such as those involving reforestation – become possible.

This study has therefore advocated that antecedent pathways of land-use/cover change must feature in any consideration of subsequent forest transitions (see also

Zweifler et al., 1994). Modern forest transitions are consequences of previous transitions in land use as much as they are events in their own right (cf. Grainger, 1995). This has several implications. For one, as pathways of land-use/cover change are arguably defined regionally (e.g., at the scale of a frontier), and not nationally, then a regional-scale approach to forest transitions is merited and likely superior to a national-scale focus in most respects (Ch.2). Second, if forest transitions are outcomes of earlier pathways of land-use/cover change and land-use transitions, then forest transitions may exhibit a diversity correspondent to the diversity of these preceding pathways (Ch.3). In this diversity, forest transitions should also exhibit varying potency and likelihood. If, then, forest transitions are diverse and differentiated outcomes of antecedent pathways and transitions of land-use/cover change as much as they are products of certain coincident factors such as urbanization and agricultural intensification, then the study of forest transitions would do well to proceed relative to a regional typology of pathways of land-use/cover change (Ch.3, Sec.6). This would allow for more appropriate comparisons of cases, untangle conflicting findings from different regions and permit more accurate predictions of reforestation. Also, in associating pathways of land-use/cover change with the pathways of reforestation specific to them, policymakers may better learn to 'piggyback' reforestation incentives on ongoing land-use changes. Though the definition of mutually exclusive 'pathways' and their distinction from 'patterns', 'trends' or 'trajectories' of land-use/cover change is problematic and probably more of a semantic matter, a shortlist of common 'pathways' might include: the hollow frontier forest conversion in Latin American forest frontiers (e.g, this study), part-time agriculture amongst a well-established rural population increasingly involved in part-time or seasonal non-farm economic activity (e.g., Bauch, 2007; Klooster, 2003; Waters, 1997), and agricultural intensification in lowlands adjacent to cultivated highlands (e.g., Jackson et al., 1998). Each of these scenarios may also be sub-divided in terms of whether they are forest abundant or forest scarce.

Though the historic forest transitions of temperate nations developed gradually (Mather, 1992; Mather and Needle, 1998), this study suggests that pathways of reforestation may emerge from antecedent pathways of land-use/cover change in less than a decade. Nascent forest transitions in South Asia and parts of South East Asia are consistent with this observation, though there deforestation also expanded gradually and continually to such an extent that denuded landscapes gave added incentive to reforest (Rudel, 2005). As the Joint Forest Management Agreements of South Asia and small-scale agriculturalists of South East Asia attest, in denuded contexts the agents of reforestation may differ little from previous agents of deforestation (Ch.3, Sec. 2.0). In the forest-abundant and recently-settled Bayano-Darién frontier, in contrast, the agents of reforestation are markedly distinct from the agents of deforestation despite the fact that, like in South and South East Asia, the pathway of reforestation mimics the antecedent pathway of deforestation. Thus, though pathways of reforestation emerge from pathways of deforestation as agents of forest-cover change combine altered environmental conditions and economic opportunities with inherited pathways of LUCC, there is no certainty that agents of reforestation will be the same as agents of deforestation. To the extent that agents of deforestation vary in whether they also become agents of reforestation, the forest transition displays a further diversity related to antecedent conditions.

This study observes that the principal correlates of the forest transition (see Mather and Needle 1998; Perz, 2007; Rudel et al., 2005; Rudel 1998) apply only weakly to the Bayano-Darién in particular and Latin American frontiers in general. Forest-to-pasture conversion may continue even with depopulation. If not, the extensive nature of pasture may still dampen the effects of reduced pressure on the land (Ch.3, Sec.6.3), as supposedly caused by the off-farm employment or emigration of some household members. Cattle ranching competes directly with other land uses that might entail increased forest cover and, in the absence of alternative investments, off-farm income may only further expand ranching operations (Reardon and Vosti, 1995; cf. Reardon et al., 1994). Even *colonos* living off marginal lands and having off-farm income are unlikely allow their lands to reforest, as off-farm income generally lacks the security and consistency to justify the abandonment or neglect of lands. Almost by definition, *colonos* lack alternative livelihoods and the skills to acquire them, (also see Heckadon Moreno, 1984 for discussions of land scarcity as a factor of colonization), and most *colonos* already live off lands that are marginal in the sense in that they are unimproved, remote and/or poorly maintained. Thus, the reach of key correlates of the forest transition, such as urban-sector growth or agricultural intensification, may not extend to *colonos*.

This study also observes deforestation in the frontier as an almost-inevitable result of humans' presence therein. Not all *colonos* deforested[23], and that those that did deforest did so in proportional to their endowment of natural and household resources. Still, the resources implicit to deforestation, namely land and labour, were common, and

23 Of those that did not deforest ≥ 5 ha over the period 2000-2006, half had landholdings of 4 ha or less.

all evidence suggests that *colonos* value forest cover more as an input to their farm system than as a standing resource. This assertion, however, should not be taken as support for a renewed 'fines and fences' conservation tactic (Wilshusen et al. 2002). Though a more active government presence in Eastern Panama would no doubt aid conservation, it alone cannot contain *colonos'* economic impetus to deforest. Rather, *colonos*' economic impetus underscores the economic foundation that any solution to deforestation will require. This thesis discussed subsidized incentives for reforestation (Vosti et al., 2003) and payments made to landholders for avoided deforestation (Coomes et al., in press). The former seems unlikely to alter *colonos'* behaviour, but the later has already proven successful in Costa Rica (Berti, 1999) and appears promising for a wider application (Chomitz et al. 2006; Coomes et al., 2003). The Bayano-Darién demonstrates that, in a frontier context where *colonos'* economic impetus is orientated almost exclusively towards forest conversion, avoided deforestation may be essential if reforestation is not to be in vain.

Optimistically, this study demonstrates that financial incentives can spur significant reforestation among large commercial interests in the frontier. It is ironic that whereas foreign enterprises increasingly influence deforestation (Rudel, 2007), they also appear as the most promising agents of reforestation in forest frontiers (cf. Potter and Lee, 1998). No evidence exists from Panama or other forest-abundant regions that such agents can effect net reforestation, particularly when counteracted by smallholders. It is sobering that genuine forest transitions – and particularly those in which tree plantations feature prominently – generally occur only after forest cover has declined to a fraction of its previous extent (Rudel et al. 2005). The Greater Bayano Region currently boasts 50 percent forest cover[24] (Ch. 2) and Panama 57 percent[25] forest cover (FAO, 2005: 194), relatively large proportions for developing tropical nations. Still, Panama's annual deforestation rate has declined from 1.9 percent[26] to 0.2 percent to 0.1[27] percent over the respective periods 1981-1990, 1990-2000 and 2000-2005 (FAO, 1993; FAO, 2005: 200). Deforestation continues at a much more hurried pace in forest-abundant Eastern Panama, though reforestation characterizes much of the long-settled and relatively denuded interior provinces (Ch. 3, Fig.11). This flux of reforestation and deforestation does not appear as a chance event, and Panama may indeed be the most forested nation

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24 Much of this area is the Comarca de Magrundandi Kuna indigenous reserve.

25 This figure includes areas in tree plantations.

26 This figure reflects changes to natural forest cover only.

27 The deforestation rates 0.2% per annum and 0.1% per annum include areas in tree plantation.

heading toward a genuine forest transition despite its abundant forest cover. As such, Panama and its regions should continue to prove illuminating case studies of the forest transition.

Literature Cited

Abizaid, C. and Coomes, O.T., 2004. Land use and forest fallowing dynamics in seasonally dry tropical forests of the southern Yucatán Peninsula, Mexico. *Land Use Policy*, 21: 71-84.

Achard, F., Eva, H.D., Mayaux, P., Stibig, J.-J. and Alan, B., 2004. Improved estimates of net carbon emissions from land cover change in the tropics for the 1990s. *Global Biogeochemical Cycles*, 18(2, May): GB200810.1029/2003GB002142.

Adames, A.J., De la Rosa, M. and Vesquez, M., 2001. Manejo integral de la cuenca del Rio Bayano, subcuenca del Rio Majé y areas adyacentes al embalse. Monographia Scientia No.1, Mayo 2001, Revista de Investigación de la Universidad de Panamá

Agrawal, A., 2000. Small is beautiful, but is larger better? Forest management institutions in the Kumaon Himalaya, India. In: C. Gibson, M. McKean and E. Ostrom (Editors), *People and Forests: Communities, Institutions and Governance*. MIT Press, Cambridge, MA, pp. 57-86.

Aide, T., Zimmerman, J., Pascarella, J., Riveira, I. and Marcano-Vega, H., 2001. Forest regeneration in a chronosequence of tropical abandoned pastures. *Restoration Ecology*, 8: 328-38.

Alexandratos, N., 1999. World food and agriculture: outlook for the medium and longer term. *Proceedings of the National Academy of Science of The United States of America*. 96: 5908-14.

Alston, L.J., Libecap, G.D. and Schneider, R., 1993. The settlement process, property rights and use on the Brazilian Amazon frontier: preliminary results and lessons from US economic history. In *All-University of California Economic History Conference*, Pasadena, California.

Alston, L.J., Libecap, G.D. and Schneider, R., 1996. The determinants and impact of property rights: land titles on the Brazilian frontier, NBER Working Paper No. 5405.

Autoridad Nacional del Ambiente (ANAM). 2003. Fortalecimiento institutional de sistema de información geográfica de la ANAM para la evaluación y monitoreo de los recursos forestales da Panamá con miras a su manejo sostenible – Informe final de resultados de la cobertura boscosa y uso del suelo de la República de Panamá: 1992-2000, ANAM y ITTO: Panamá. Data available at: http://www.anam.gob.pa/ Sif%202002/index.htm, http://www.ccad.ws/capacitacion.html

Autoridad Nacional del Ambiente (ANAM) 2006. *Indicadores Ambientales de la República de Panamá, 2006: Superficie Reforestada – Porcentaje de la Superficie Reforestada en la Repüblica de Panamá, Según Especie, Años 1992-2004,* Accessed 19/02/2006, Text and graphs available at: http://www.anam.gob.pa/indicadores/index.htm.

Angelsen, A., and D. Kaimowitz. 1999. Rethinking the causes of deforestation: lessons from economic models. *The World Bank Research Observer.*14: 73-98.

Arroyo-Mora, J.P., Sánchez-Azofeifa, A., Rivard, B., Calvo, J.C. and Janzen, D.H., 2005. Dynamics in landscape structure and composition for the Chorotega region, Costa Rica, from 1960 to 2000. *Agriculture, Ecosystems & Environment*, 106: 27-39.

Bajarcharya, D., 1983. Fuel, food or forests? Dilemmas in a Nepali Village. *World Development*, 11(2): 1057-74.

Baptista, S.R. and Rudel, T.K., 2006. A re-emerging Atlantic forest? Urbanization, industrialization and the forest-transition in Santa Catarina, southern Brazil. *Environmental Conservation*, 33(3): 195-202.

Barbier, E.B., 2004. Agricultural expansion, resource booms and growth in Latin America: implications for long-run economic development. *World Development*, 32(1): 137.

Barlett, P.F., 1976. Labour efficiency and the mechanism of agricultural evolution. *Journal of Anthropological Research*, 32(2): 124-40.

Barlett, P.F., 1977. The structure of decision making in Paso. *American Ethnologist*, 4(2): 285-307.

Barlett, P.F., 1980. Cost-benefit analysis: a test of alternative methodologies. In: P.F. Barlett (Editor), *Agricultural Decision Making: Anthropological Contributions to Rural Development*. Academic Press, Toronto, pp. 137-60.

Barlett, P.F., 1982. *Agricultural Choice and Change: Decision Making in a Costa Rican Community*. Rutger's University Press, New Brunswick, New Jersey.

Bauch, P., 2007. Interactions of payment for hydrological services and forest transitions: a case study of the Rio Cuale Watershed. MA Thesis, Department of Geography, McGill University, Montreal, Canada.

Berti, C.G., 1999. Transformaciones recientes en la industria y la politica forestal costarricanse y sus implicaciones para el desarrollo de los bosques secundarios. MSc Thesis, CATIE, Turrialba, Costa Rica.

Bilsborrow, R.E., 1987. Population pressures and agricultural development in developing countries: A conceptual framework and recent evidence. *World Development*, 15(2): 183-203.

Binswanger, F., 1991. Brazilian policies that encourage deforestation in the Amazon. *World Development*, 19(7): 821-9.

Boserup, E., 1965. *The conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure*. Aldine Pub. Co., Chicago.

Boserup, E., 1981. *Population and Technological Change: A Study of Long-Term Trends*. University of Chicago Press, Chicago.

Brook, B.W., Bradshaw, C.J.A., Koh, L.P. and Sodhi, N.S., 2006. Momentum drives the crash: mass extinction in the tropics. *Biotropica*, 38(3): 302-5.

Browder, J. O., and B. J. Godfrey. 1997. *Rainforest Cities: Urbanization, Development and Globalization of the Brazilian Amazon*. Columbia University Press, New York.

Brown, J. C. 2005. Soybean production and conversion of tropical forests in the Brazilian Amazon: the case of Vihena, Rodônia. *Ambio*. 34: 462-9.

Brown, L., Sierra, R., DiGiacinto, S. and Smith, W., 1994. Urban system evolution in the frontier setting. *Geographical Review*, 84(3): 249-65.

Brown, J. C., W. Jepson, and K. P. Price. 2004. Expansion of mechanized agriculture and land-cover change in southern Rodônia, Brazil. *Journal of Latin American Geography*. 3(1): 96-102.

Burt, J.E. and Barber, G.M., 1996 *Elementary Statistics for Geographers,* Guildord Press, New York.

Cabrita, R., 1980. *Posibilidades del Desarrollo de un Modelo Agroforestal en el Darién, Panamá*, United Nations Food and Agricultural Organization, Panama.

Camara-Cabrales, L., 1999. Small farmer migration and the agroforestry alternative in the Panama Canal Watershed. *Journal of Sustainable Forestry*, 8(3-4): 11-22.

Carr, D. L. 2004. Proximate population factors and deforestation in tropical agricultural frontiers. *Population and Environ*ment. 25: 585-612.

Chayanov, A.V., 1966 [1925]. *The Theory of Peasant Decision* Making. Irwin, Homewood, IL.

Chazdon, R.L., 2003. Tropical forest recovery: legacies of human impact and natural disturbances. *Perspectives on Plant Ecology, Evolution and Systematics*, 6: 51-71.

Chomitz, K.M., Buys, P., De Luca, G., Thomas, T.S. and Wertz-Kanounnikoff, S., 2006. At loggerheads? Agricultural expansion, poverty reduction and environment in tropical forests. a world bank policy research report (Oct 23). World Bank, Washington, D.C. Available at: http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTPRRS/EXTTROPICALFOREST/0,,menuPK:2463898~pagePK:64168092~piPK:64168088~theSitePK:2463874,00.html.

Collier, G., Mountjoy, D. and Nigh, R., 1994. Peasant agriculture and global change: a Maya response to energy development to Southeastern Mexico. *Bioscience*, 44(6): 398-407.

Controlaria. 1991a. Censo Nacional Agropecuario. Dirección de Estadísticas y Censo, República de Panamá.

Controlaria. 1991b. Censos Nacionales de Población y Vivienda. Dirección de Estadísticas y Censo, República de Panamá.

Controlaria. 2001a. Censo Nacional Agropecuario. Dirección de Estadísticas y Censo, República de Panamá.

Controlaria. 2001b. Censos Nacionales de Población y Vivienda. Dirección de Estadísticas y Censo, República de Panamá

Coomes, O., Grimard, F., Potvin, C. and Sima, P., in press. The fate of tropical forests: carbon or cattle? *Ecological Economics*.

Coomes, O.T. and Burt, G.J., 1997. Indigenous market-oriented agroforestry: dissecting local diversity in western Amazonia. *Agroforestry Systems*, 37: 27-44.

Dagang, A.B.K., Herrera, F. and Gonzalez, R., 2003. Unbridled expansion and the continuation of the conquest: the agricultural frontier and consequences for the environment and indigenous population in Eastern Panama, The 2003 Meeting of the Latin American Studies Association, Dallas, Texas, March 27-29, 2003.

de Janvry, A., Sadoulet, E. and Wilcox, L.Y., 1989. Land and labour in Latin American agriculture from the 1950s to the 1980s. *The Journal of Peasant Studies*, 16(3): 398-424.

Delgado, C., M. Rosegrant, H. Steinfield, S. Ehui, and C. Courbois. 1999. Livestock to 2020: The Next Food Revolution. 2020 Vision for Food Agriculture and the Environment Discussion Paper 28. International Food Policy Research Institute, Washington, D.C.

De Janvry, A., 1981. *The Agrarian Question and Reformism in Latin America*. The Johns Hopkins University Press, Baltimore.

Dufor, D.L. 1990 Use of tropical rainforest by native Amazonia. *Bioscience* 40(9): 652-59

Ewers, R.M., 2006. Interaction effects between economic development and forest cover determine deforestation rates. Gl*obal Environmental Change*, 16: 161-69.

FAO, 1993. *Tropical Forest Resource Assessment 1990*, Food and Agricultural Organization of the United Nations, Rome, http://www.fao.org/docrep/007/t0830e/t0830e00.htm.

FAO, 2001. Forest Resource Assessment 2000. Forestry Paper No. 140, Food and Agricultural Organization of the United Nations, Rome.

FAO, 2006. Global Forest Resource Assessment 2005: Progress Toward Sustainable Forest Management, FAO Forestry Paper No. 147, Food and Agricultural Organization of the United Nations, Rome, http://www.fao.org/forestry/site/fra2005/en/.

Fearnside, P.M., 1987. Rethinking continuous cultivation in Amazonia. *BioScience*, 37(3): 209-13.

Fearnside, P.M., 1997. Deforestation in the Brazilian Amazon: history, rates and consequences. *Conservation Biology*, 19(3): 680-688.

Fearnside, P.M., 2001. Soybean cultivation as a threat to the environment in Brazil. *Environmental Conservation*, 28(1): 23-38.

Foster, A. and Rosenzweig, M.R., 2003. Economic growth and the rise of forests. *The Quarterly Journal of Economics*, 118: 601-37.

Foweraker, J., 1981. *The Struggle for Land*. Cambridge University Press, Cambridge.

Fox, J., 1993. Forest resources in a Nepali village in 1980 and 1990: the positive influence of population growth. *Mountain Research and Development*, 13(1): 89-98.

Geist, H. and Lambin, E.F., 2002. Proximate causes and underlying driving forces of tropical deforestation. *BioScience*, 52(2): 143-50.

Geohegan, J. et al., 1998. "Socializing the Pixel" and "Pixelizing the Social" in Land-Use and Land-Cover Change. In: D. Liverman, E.F. Moran, R. Rindfuss and P.C. Stern (Editors), *People and Pixels: Linking Remote Sensing and Social Science*. National Academy Press, Washington, D.C., pp. 51-69.

Grainger, A., 1995. The forest transition: an alternative approach. *Area*, 27(3): 242-51.

Green, J. and Garcia de Paredes, R., 1969. Panamanian District: A Case Study in the Sociology of Development, United States Agency for International Development, Panama.

Gudeman, S., 1978. *The Demise of a Rural Economy: From Subsistence to Capitalism in a Latin American Village*. Routledge & Keagan Paul, London.

Hamilton, N. and Chinchilla, N.S., 1991. Central American migration: a framework for analysis. *Latin American Research Review*, 26(1): 75-110.

Healey, S.P. and Gara, R.J., 2003. The effect of a teak (Tectona grandis) plantation on the establishment of native species in an abandoned pasture in Costa Rica. *Forest Ecology and Management*, 176(1-3): 497-507.

Hecht, S.B., 1985. Environment, development and politics: capital accumulation and the livestock sector in Eastern Amzonia. *World Development*, 13(6): 663-84.

Hecht, S.B., 2004. Invisible forests: the political ecology of forest resurgence in El Salvador. In: R. Peet and W. Watts (Editors), *Libearation Ecologies: Environment, Development and Social Movements* (2nd ed.). Routledge, London, pp. 64-103.

Hecht, S.B., 2005. Soybeans, development and conservation on the Amazon frontier. *Development and Change*, 36(2): 375-404.

Hecht, S.B., Anderson, A. and May, P., 1988. The subsidy from Nature: shifting cultivation, successional palm forests, and rural development. *Human Organization*, 27(1): 25-35.

Heckadon Moreno, S., 1979. Santeño colonization of tropical forests in Panamá: a peasant economy and natural resources, In *Proceedings of the Conferences on the Development of Amazonia in Seven Countries, 23-26 September 1979*, University of Cambridge, Cambridge.

Heckadon Moreno, S., 1981. La colonizacion campesina de bosques tropicale en Panama. *Estudios Rurales Latinoamericanos*, 4(3): 287-306.

Heckadon Moreno, S., 1981a. Dinámica social de la cultura del potrero en Panamá, RENARE, Panama.

Heckadon Moreno, S. and McKay, A. (Editors), 1984. *Colonizacion y Destruction de Bosques en Panama: Ensayos Sobre un Grave Problema Ecológico*. Asoociación Panameña de Antropología, Panamá.

Henkel, R., 1971. The Chapare of Bolivia: A study of tropical agriculture in transition, PhD Dissertation, University of Wisconsin, Madison, WI.

Herlihy, P.H., 1987. A cultural geography of the Embera and Wounan (Choco) Indians of Darien, Panama, with emphasis on recent village formation and economic diversification. PhD Dissertation. Louisiana State University and Agricultural and Mechanical College, Baton Rouge, LA.

Herrera, F., 1986. Análisis socioeconómico de la Cuana Alta del Bayano, *Memorias del Taller Sobre la Próblematica de la Cuenca Hidrográfica de Bayano*. Centro Agronómico Tropical de Investigación y Ensañanza, San José, Costa Rica, pp. 121-67.

Hussain, W.F., Amachar, G. and Magrath, W., 1999. We are all part of the same 'kudrat': community forest management in Rajaji National Park. *Forest, Trees and People*, 38: 35-8.

Imbernon, J., 1999. A comparison of the driving forces behind deforestation in the Peruvian and the Brazilian Amazon. *Ambio*, 28(6): 509-513.

Instituto de Recursos Eléctricos e Hidrólogicos (IRHE) 1978. Aspectos Sociales de la Reubicacion de la Poblacion del Bayano – Mirada Retrospectiva. *En*: Lago Bayano: Formacion, Manejo y Control. *Dirigido por* La Mesa Rondonda Organizado por el Instituto de Recursos Hidraulicos y Electrificación, Sesión de Dr. Claude Betts, Ing. Dionisio Batista, Sr. Francisco Herrera, Licdo. Aníbal Pastor. Instituto de Recursos Hidráulicos y Electrificación, Ciudad de Panama, 11 al 13 de enero de 1978, pp. 119-132.

Jones, J.R., 1988. Colonization in Central America. In: W. Manshard and W.B. Morgan (Editors), *Agricultural Expansion and Pioneer Settlements in the Humid Tropics: Selected Papers at a Workshop Held in Kuala Lumpur, 17-21 September 1985*. United Nations University, Tokyo.

Jones, J.R., 1989. Human settlement and tropical colonization in Central America. In: D.A. Schumann and W.L. Partridge (Editors), *The Human Ecology of Tropical Land Settlement in Latin America*. Westview, Boulder, CO, pp. 43-85.

Jones, J.R., 1990. *Colonization And Environment: Land Settlement Projects in Central America*. United Nations University Press, Tokyo.

Kay, C., 2000. Latin America's agrarian transformation: peasantization and proletarianization In: D. Bryceson, C. Kay and J. Mooij (Editors), *Disappearing Peasantries? Rural Labour in Africa, Asia and Latin America*. Intermediate Technology Publications, London, pp. 123-38.

Kinsey, B.H. and Binswanger, H.P., 1993. Characteristics and performance of resettlement programs: a review. *World Development*, 21(9): 1477-94.

Klooster, D., 2000. Beyond deforestation: the social context of forest change. *Conference of American Geographers*, 26: 47-59.

Klooster, D., 2003. Forest transitions in Mexico. *Professional Geographer*, 55(2): 227-37.

Kramer, R., Richter, D., Pattanayak, S. and Sharma, D., 1997. Ecological and economic analysis of watershed protection in Eastern Madagascar. *Journal of Environmental Management*, 49: 277-95.

Kummer, D., Concepcion, R. and Canizares, B., 1994. Environmental degradation in the uplands of Cebu. *Geographical Review*, 84(3): 226-76.

Lamb, D., Erskine, P.D. and Parrotta, J.A., 2005. Restoration of degraded tropical forest landscapes. *Science*, 310: 1628-32.

Lamb, D. and Gilmour, D., 2003. *Rehabilitation and Restoration of Degraded Forests*. Issues in Forest Conservation Series. International Union for Conservation of Nature (IUNC) and the World Wildlife Fund (WWF), Gland, Switzerland, http://app.iucn.org/dbtw-wpd/edocs/FR-IS005.pdf#search=%22rehabilitation%20 and%20restoration%20of%20degraded%20forests%22.

Lambin, E.F. et al., 1999. Land-Use and Land-Cover Change (LUCC) Implementation Strategy. International Geosphere-Biosphere Programme Report No. 48, International Human Dimensions Programme on Global Environmental Change Report No. 10. Available at: http://www.geo.ucl.ac.be/LUCC/ implstrategy/implementation.html.

Lambin, E.F., Turner, B.L. and Geist, H., 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change*, 11(4): 261-69.

Lambin, E.F., Geist, H.J. and Lepers, E., 2003. Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, 28: 205-41.

Ledec, G., 1992. The role of bank credit for cattle raising in financing deforestation: an economic case study from Panama, PhD Dissertation, University of California, Berkeley, CA, pp. 310 pp.

Lugo, A.E., 1997. The apparent paradox of reestablishing species richness on degraded lands with tree monocultures. *Forest Ecology and Management*, 99: 9-19.

Lugo, A.E. and Helmer, E., 2004. Emerging forests on abandoned land: Puerto Rico's new forests. *Forest Ecology and Management*, 190: 145-161.

Mather, A.S., 1992. The forest transition. *Area*, 24: 367-79.

Mather, A.S., 2005. Assessing the world's forests. *Global Environmental Change*, 15: 267-280.

Mather, A.S. and Needle, C.L., 1998. The forest transition: a theoretical basis. *Area*, 30(2): 117-24.

Mather, A.S. and Needle, C.L., 1999. Environmental Kuznets curves and forest trends. *Geography*, 84: 55-65.

Maxwell, S., 1980. Marginalized colonists to the north of Santa Cruz: avenues of escape from the barbecho crisis. In: F. Barbira-Scazzocchio (Editor), *Land, People and Planning in Contemporary Amazonia*. Cambridge University Press, Cambridge, pp. 162-70.

Maxwell, S. and Pozo, M., 1981. Farming systems in the colonization crescent of Santa Cruz, Bolivia: results of a survey. Working Document No. 22, CIAT, Santa Cruz, Bolivia.

McCracken, S.D., Brondizio, E., Nelson, D., Siqueira, A.D. and Rodriguez-Pedraza, C., 1999a. Remote sensing and GIS at the farm property level: demography and deforestation in the Brazilian Amazon. *Photogrammetric Engineering and Remote Sensing*, 65: 1311-20.

McCracken, S.D., Siqueira, A., Moran, E. and Brondizio, E., 1999b. Domestic life course and land use practices: a conceptual framework and examples, The 48th Annual Latin American Studies Conference, "Patterns and Processes of Land Use and Forest Change in the Amazon", University of Florida.

McKay, A., 1973. Colonización de tierras nuevas en Panamá. *Revista Panameña de Antropología,* 1: 35-55.

McKay, A., 1976. El Exodo Rural en Panamá*, Actas del II Simposium Nacional de Antropología, Arqueología y Etnohistoría de Panamá*. Universidad de Panama, Panama.

McKay, A., 1984. Colonización de tierras nuevas en Panamá. In: S. Heckadon Moreno and A. McKay (Editors), *Colonizacion y Destruccion de Bosques en Panama: Ensayos Sobre un Grave Problema Ecologico*. Asociación Panamña de Antropologia, Panama, pp. 45-62.

Mertens, B., Poccard-Chapuis, R., Piketty, M.G., Lacques, A.E. and Venturieri, A., 2002. Crossing spatial analyses and livestock economics to understand deforestation processes in the Brazilian Amazon: the case of Sao Felix do Xingu in South Para. *Agricultural Economics*, 27(3): 269.

Moran, E.F., 1981. *Developing the Amazon*. Indiana University Press, Bloomington.

Moran, E., Brondizio, E., Mausel, P. and Wu, Y., 1994. Integrating Amazonian vegetation, land use and satellite data. *BioScience*, 44(5): 329-38.

Moran, E.F., Packer, A., Brondizio, E. and Tucker, J., 1996. Restoration of vegetation cover in eastern Amazon. *Ecological Economics*, 18: 41-54.

Moran, E.F. and Brondizio, E., 1998. Land-use change after deforestation in Amazonia. In: D. Liverman, E.F. Moran, R. Rindfuss and P. Stern (Editors), *People and Pixels: Linking Remote Sensing and Social Science*. National Academy Press, Washington, D.C., pp. 94-120.

Molotch, H., Freudenburg, W. and Paulsen, K., 2000. History repeats itself, but how? *American Sociological Review*, 65(6): 791-823.

Müller, D. and Zeller, M., 2002. Land use dynamics in the central highlands of Vietnam: a spatial model combining village survey data with satellite imagery interpretation. *Agricultural Economics*, 27: 333-54.

Neil, R.E., 1984. What makes history happen? In: D.C. Korten and R. Klauss (Editors), *People-Centered Development: Contributions Toward Theory and Planning*. Kumarian Press, West Hartford, Connecticut.

Nepstad, D., Moreira, A.G. and Alencar, A.A., 1999. *Flames In The Rain Forest: Origins, Impacts And Alternatives To Amazonian Fires*. The World Bank, Brasilia.

Orgega, E., 1992. Evolution of the rural dimension in Latin America and the Caribbean. *CEPAL Review*, 47: 115-36.

Ortiz, S., 1984. Colonization of the Columbian Amazon. In: M. Schmink and C. Wood (Editors), *Frontier Expansion in Amazonia*. Westview Press, Boulder, CO, pp. 204-230.

O'Brien, K., 1999. *Sacrificing the Forest: Environmental and Social Struggles in Chiapas*. Westview Press, Boulder, CO.

Partridge, W.L., 1984. The humid tropics cattle ranching complex: cases from Panama reviewed. *Human Organization*, 43(1): 75-9.

Perz, S.G., 2007. Grand theory and context-specificity in the study of forest dynamics: forest transition theory and other directions. *The Professional Geographer*, 59(1): 105-14.

Perz, S.G. and Walker, R.T., 2002. Household life cycles and secondary forest cover among small farm colonists in the Amazon. *World Development*, 30(6): 1009-27.

Perz, S.G. and Skole, D.L., 2003. Social determinants of secondary forests in the Brazilian Amazon. *Social Science Research*, 32: 25-60.

Pichón, F.J., 1997. Colonist land allocation decisions, land use, and deforestation in the Ecuadorian Amazon frontier. *Economic Development and Cultural Change*, 45: 707-44.

Pichón, F.J., 1997. Settler households and land-use patterns in the Amazon frontier: farm-level evidence from Ecuador. *World Development*, 25(1): 67-91.

Pinstrup-Anderson, P., R. Pandya-Lorch, and M. W. Rosegrant. 1997. The World Food Situation: Recent Developments, Emerging Issues, and Long-Term Prospects*,* 2020 Vision Food Policy Report. International Food Policy Research Institute, Washington, D.C.

Pinstrup-Anderson, P., R. Pandya-Lorch, and M. W. Rosegrant. 1999. World Food Prospects: Critical Issues for the Early Twenty-First Century*,* 2020 Vision Food Policy Report. International Food Policy Research Institute, Washington, D.C.

Potter, L. and Lee, J., 1998. Tree planting in Indonesia: trends, impacts and directions. Ocasional paper #18, Center for International Forestry Research, Bogor, Indonesia. Available online at: http://www.cifor.cgiar.org/Publications/Papers/ocpapers/

Potvin, C., Tschakert, P., Lebel, F., Kirby, K., Barrios, H., Bocariza, J., Caisamo, J., Caisamo, L., Casamá, J., Casamá, M., Chamorra, L. Dumasa, N., Goldenberg, S., Guaninora, V., Hayes, P., Moore, T., Ruíz, J., in press. A participatory approach to the establishment of a baseline scenario for a reforestation Clean Development Mechanism. *Mitigation and Adaptation Strategies for Global Change.* doi: 10.1007/s11027-006-9056-3

Preston, D., 1990. From hacienda to family farm: changes to environment and society in Pimampiro, Ecuador. *The Geographic Journal*, 15(1): 31-38.

Preston, D., 1998. Post-peasant capitalist graziers: the 21st Century in Southern Bolivia. Mou*ntain Research and Development*, 18: 151-58.

Rattner, H., 1988. The colonization and occupation of the Brazilian Amazonia. In: W. Manshard and W.B. Morgan (Editors), *Agricultural Expansion and Pioneer Settlements in the Humid Tropics: Selected Papers at a Workshop Held in Kuala Lumpur, 17-21 September 1985*. United Nations University, Tokyo.

Reardon, T., Crawford, E. and Kelly, V., 1994. Links between non-farm income and farm investment in African households: adding the capital market perspective. *American Journal of Agricultural Economics*, 76(5): 1172-6.

Reardon, T. and Vosti, S.A., 1995. Links between rural poverty and the environment in developing countries: Asset categories and investment poverty. *World Development*, 23(9): 1495-1506.

Richards, J.A., 1993. *Remote Sensing and Digital Image Analysis*. Springer-Verlag, New York.

Rock, M., 1996. The stork, the plow, the rural social structure, and tropical deforestation in poor countries. *Ecological Economics*, 18: 113-31.

Rudel, T.K., 1998. Is there a forest transition? Deforestation, reforestation and development. *Rural Sociology*, 63: 533-52.

Rudel, T.K., 2005. *Tropical Forests: Regional Paths of Destruction and Regeneration in the Late Twentieth Century*. Columbia University Press, New York.

Rudel, T.K., 2007. Changing agents of deforestation: from state-initiated to enterprise driven processes, 1970-1990. *Land Use Policy*, 24: 35-41.

Rudel, T. K., and C. Fu. 1996. A requiem for southern regionalists: reforestation in the South and the uses of regional science. *Social Science Quarterly*. 77: 804-20.

Rudel, T.K., Perz-Lugo, M. and Zichal, H., 2000. When fields revert to forests: development and spontaneous reforestation in post-war Puerto Rico. *Professional Geographer*, 52(3): 386-97.

Rudel, T.K., Bates, D. and Machinguishi, R., 2002. A tropical forest transition? Agricultural change, out-migration, and secondary forests in the Ecuadorian Amazon. *Annals of the Association of American Geographers*, 92(1): 87-102.

Rudel, T. K.; Coomes, O. T.; Moran, E.; Achard, F.; Angelsen, A.; Xu, J.; and Lambin, E. 2005. Forest transitions: towards a global understanding of land use change. *Global Environmental Change Part A*. 15(1): 23-31.

Salam, M.A., Noguchi, T. and Koike, M., 2000. Understanding why farmers plant trees in the homestead agroforestry in Bangladesh. *Agroforestry Systems*, 50: 77-93.

Sánchez-Azofeifa, G.A., 2000. Land use and cover change in Costa Rica. In: C.A. Hall, P. Van Laake, C. Leon-Perez and G. Leclerc (Editors), *Quantifying Sustainable Development: The Future of Tropical Economies*. Academic Press, New York, pp. 473-501.

Schelhas, J., 1996. Land use choice and change: intensification and diversification in the lowland tropics of Costa Rica. *Human Organization*, 55(3): 298-304.

Schelhas, J. and Greenberg, R., 1996. *Forest Patches in Tropical Landscapes*. Island Press, Washington, D.C.

Schively, G. and Martinez, E., 2001. Deforestation, irrigation, employment, and cautious optimism in Southern Palawan, the Philippians. In: A. Angelsen and D. Kaimowitz (Editors), *Agricultural Technologies and Tropical Deforestation*. CAB International, New York, pp. 335-46.

Schweigert, T.E., 1992. Commercial sector wages and subsistence sector labour productivity in Guatemalan agriculture. *World Development*, 21(1): 81-91.

Schweigert, T.E., 1993. Commercial sector wages and subsistence sector labour productivity in Guatemalan agriculture. Wor*ld Development*, 21(1): 81-91.

Scudder, T., 1985. A sociological framework for the analysis of new land settlements. In: M.M. Cernea (Editor), *Putting People First: Sociological Variables in Rural Development*. Oxford University Press, Toronto, pp. 121-54.

Sikor, T. and Truong, D., 2002. Agricultural policy and land use changes in a black Thai commune of Northern Vietnam *Mountain Research and Development*, 22(3): 248-55.

Simon, M. F., and F. L. Garagorry. 2005. The expansion of agriculture in the Brazilian Amazon. *Ambio*. 32: 203-212.

Simmons, C.S., 1997. Forest management practices in the Bayano region of Panama: Cultural variations. *World Development*, 25(6): 989.

Sloan, S., 2007. Fewer people may not mean more forest for Latin American forest frontiers. *Biotropica*, 39(4): 443-6

Southworth, J. and Tucker, C., 2001. The influence of accessibility, local institutions and socio-economic factors on forest cover change in the mountains of Western Honduras. *Mountain Research and Development*, 21(3): 276-83.

Stearman, A.M., 1983. Forest to pasture: frontier settlement in the Bolivian lowlands. In: E. Moran (Editor), *The Dilemma of Amazonian Development*. Westview Press, Boulder, CO, pp. 51-63.

Steininger, M. K., C. J. Tucker, P. Ersts, T. J. Killeeen, A. Villegas, and S. B. Hecht. 2001. Clearance and fragmentation of tropical deciduous forest in the Tierras Bajas, Santa Cruz, Bolivia. *Conservation Biology*. 15(4): 856-866.

Tachibana, T., Nguyen, T. and Otsuka, K., 2001. Agricultural intensification versus extensification: a case study of deforestation in the northern hill region of Vietnam. *Journal of Environmental Economics and Management*, 41(1): 44-69.

Thiele, G., 1993. The dynamics of farm development in the Amazon: the barbecho crisis model. *Agricultural Systems*, 42: 179-97.

Tschakert, P., Coomes, O. and Potvin, C., 2007. Indigenous livelihoods, slash-and-burn agriculture and carbon stocks in Eastern Panama. *Ecological Economics*, in press

Turner, M.D., 1999. Merging local and regional analysis of land use change: the case of livestock in the Sahel. *Annals of the Association of American Geographers*, 89(2): 191-220.

Vilar, R., and B. Kupfer. 1995. *Cambios en la Agricultura Commercial de Santa Cruz en el Periodo de Ajuste Structural*. Cedla, La Paz, Bolivia.

Vosti, S.A., Muñoz Braz, E., Carpentier, C.L., D'Olivera, M.V.N. and Witcover, J., 2003. Rights to forest products, deforestation and smallholder income: evidence from the western Brazilian Amazon. *World Development*, 31(11): 1889-1901.

Wali, A., 1989. *Kilowatts and Crisis: Hydroelectric Power and Social Dislocation in Eastern Panama*. Westview Press, London.

Walker, R.T., 1993. Deforestation and economic development. *Canadian Journal of Regional Science*, 16(3): 481-97.

Walker, R.T., 1999. The structure of uncultivated wilderness: land use beyond the extensive margin. *Journal of Regional Science*, 39: 387-410.

Walker, R.T., 2004. Theorizing land-cover and land-use change: the case of tropical deforestation. *International Regional Science Review*, 27(3): 247-70.

Walker, R.T. and Homma, A.K.O., 1996. Land use and land cover dynamics in the Brazilian Amazon: an overview. *Ecological Economics*, 18: 67-80.

Walker, R.T., Moran, E. and Anselin, L., 2000. Deforestation and cattle ranching in the Brazilian Amanzon: external capital and household processes. *World Development*, 28: 683-99.

Walker, R.T., Perez, S., Caldas, M. and Guilherm Teixiera Silva, L., 2002. Land use and land cover change in forest frontiers: the role of household life cycles. *International Regional Science Review*, 25(2): 169-99.

Waters, W.F., 1997. The road of many returns: rural bases for the informal urban economy in Ecuador. *Latin American Perspectives*, 24(3): 50-64.

Williams, R.G., 1986. *Export agriculture and the crisis in Central America*. University of North Carolina Press, Chapel Hill.

Wolf, E., 1957. Closed corporate peasant communities in Mesoamerica and Central Java. *Southwestern Journal of Anthropology*, 13(1): 1-8.

Wood, C. H., and S. D. Skole. 1996. Population and land-use changes in the Brazilian Amazon. *In* S. Ramphal and S.W. Sinding (Eds.). *Population Growth and Environmental Issues*, pp. 95-108. Praeger, Westport, Connecticut.

Wood, C. H., and D. Skole, 1998. Linking satellite, census and survey data to study deforestation in the Brazilian Amazon. *In* D. Liverman, E. Moran, R. Rindfuss and P. Stern (Eds.). *People and Pixels: Linking Remote Sensing with Social Science*, pp. 70-93. National Academy Press, Washington, D.C.

Wright, J.S. and Muller-Landau, H.C., 2006. The future of tropical forest species. *Biotropica*, 38(3): 287-301

Zweifler, M.O., Gold, M.A. and Thomas, R.N., 1994. Land use evolution in hill regions of the Dominican Republic. *Professional Geographer*, 46(1): 39.

APPENDIX I

Household-Survey Form

LAND USE AND LAND COVER CHANGE IN BAYANO

Part I – Cuestionario Familiar

DETALLES PERSONALES

Nombre____

Pueblo____

Edad________________________
Fecha_____________________________________

LIFE-CYCLE VARIABLES

A1 En cual año llegó usted aquí en ________ para vivir permanentemente?					
A1.1 En cual año llegó su familia aquí en ____________ para vivir permanentemente?					
A2 Cuantos hijos tiene usted?	# Niños	Muerto?	Cuando Murió?	Edad?	Educación
	1				
	2				
	3				
	4				
	5				
	6				
	7				
	8				
	9				
	10				
	11				
	12				
A2.1 Todos son vivos?	Ve A2				
A2.3 Cuando murió este(s) niño(s)?	Ve A2				
A2.3. Cuales son las edades de cada de sus hijos	Ve A2				

(vivos)?	
A3. Tiene esposa usted?	
A3.1. Cual es la edad de su esposa?	
A4 Cuales son los niveles educativas máximos logrados por cada miembro de su familia?	Ve A2

B HOLLOW FRONTIER

B2 En la primara año que pasó usted / su padre aquí, tenia alguno de los siguientes pertenencias?	☐ Moto sierra ☐ Una vaca ☐ Un vehiculo ☐ Nevera o estufa de gas ☐ Generador de luz eléctrica
B2.1 Hoy en día tiene usted alguno de los siguientes pertenencias?	☐ Moto sierra ☐ Una vaca ☐ Un vehiculo ☐ Nevera o estufa de gas ☐ Generador de luz eléctrica
B3 Cuantos vacas tenia usted hace 5 años (2001)?	
B4 Cuantos vacas tiene usted hoy?	
B5 Cuantos vacas vendió usted hace 5 años (2001)?	1___________ 2___________ 3___________ 4___________ 5___________ 6___________ 7___________ 8___________ 9___________ 10___________ 11___________ 12___________ 13___________ 14___________ 15___________ 16___________
B5.1 Por cuantos balboas las vendió cada uno?	VE B5
B6 Cuantos vacas vendió usted hace 1 año (2005)?	1___________ 2___________ 3___________

	4__________ 5__________ 6__________ 7__________ 8__________ 9__________ 10__________ 11__________ 12__________ 13__________ 14__________ 15__________ 16__________
B6.1 Por cuantos balboas las vendió cada uno?	VE B6

C FOREST TRANSITION

C1 Tiene usted miembro(s) de su familia que vive fuera el pueblo?	
C1.1 Cuantos miembros de su familia viven fuera el pueblo?	
C1.2 En cual año salió / salieron el pueblo para vivir afuera? En cual mes?	Año Mes 1__________ 2__________ 3__________ 4__________
C2 Tiene miembros de su familia que trabajan fuera el pueblo / casa?	
C2.1 Cuantos miembros de su familia trabajan fuera el pueblo / casa para un sueldo?	
C2.2 Para cuantos meses por año trabajan fuera el pueblo / casa para un sueldo?	
C2.3 En cual año salió / salieron el pueblo / casa para trabajar? En cual mes?	Año Mes 1__________ 2__________ 3__________ 4__________
C2.4 El / Ella / Ellos envía(n) parte de su	

salario a su familia en el pueblo?	
C2.5 Por el promedio, cuanto le envia el / ella por mes?	
C3 En el año pasado, cuanto ganó usted, por mes?	
C4 En el año pasado cuantos peones empleó en su terreno?	
C5 En el año pasado, cuanto balboas gastó usted en abonos químicas o la fumigación usted?	

LAND USE AND LAND COVER CHANGE IN BAYANO

Part II – Cuestionario Sobre los Parcelas de Tierra

CA = Cultivos Anuales BR = Barbecho Rastrojo P = Pasto TA = Tierra Arrendad
CP = Cultivos Perennales B = Bosque D= Degradado m = cultivado a media

Plot	Titulado?	Presente		Hace 1 Año		Hace 2 Años		Hace 3 Años	
	Cuando	**Cobertura**	**Area**	**Cobertura**	**Area**	**Cobertura**	**Area**	**Cobertura**	**Area**
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									

Plot	Hace 4 Años		Hace 5 Años		Hace 6 Años		Hace 7 Años	
	Cobertura	Area	Cobertura	Area	Cobertura	Area	Cobertura	Area
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Plot	Hace 8 Años		Hace 9 Años		Hace 10 Años		Hace 11 Años	
	Cobertura	Area	Cobertura	Area	Cobertura	Area	Cobertura	Area
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Plot	Hace 12 Años		Hace 13 Años		Hace 14 Años		Hace 15 Años	
	Cobertura	Area	Cobertura	Area	Cobertura	Area	Cobertura	Area
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Plot	Hace 16 Años		Hace 17 Años		Hace 18 Años		Hace 19 Años	
	Cobertura	Area	Cobertura	Area	Cobertura	Area	Cobertura	Area
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Plot	Hace 20 Años		Hace 21 Años		Hace 22 Años		Hace 23 Años	
	Cobertura	Area	Cobertura	Area	Cobertura	Area	Cobertura	Area
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

APPENDIX II

Ethics Approval for Research

01/29/07 16:34 FAX 514 398 7437 McGILL-GEOGRAPHY 002

FROM :STRI TUPPER FAX NO. :507 2128148 Jan. 24 2007 12:39PM P2

Page 2 of 2
Sean Sloan

McGill University

ETHICS REVIEW
RENEWAL REQUEST/FINAL REPORT

Continuing review of human subjects research requires, at a minimum, the submission of an annual status report to the REB. This form must be completed to request renewal of ethics approval. If a renewal is not received before the expiry date, the project is considered no longer approved and no further research activity may be conducted. When a project has been completed, this form can also be used as a Final Report, which is required to properly close a file. To avoid expired approvals and, in the case of funded projects, the freezing of funds, this form should be returned 3-4 weeks before the current approval expires.

REB File #: 180-0306
Project Title: Colonization, land use and land-cover change in the Bayano Region, Panama
Principal Investigator: Sean Sloan 260156884
Department/Phone/Email: Geography / +(507) 6721-5224
Faculty Supervisor (for student PI): Oliver T. Coomes

1. Were there any significant changes made to this research project that have any ethical implications? ___Yes _X___No
If yes, describe these changes and append any relevant documents that have been revised.

2. Are there any ethical concerns that arose during the course of this research? ___ Yes __ X_ No. If yes, please describe.

3. Have any subjects experienced any adverse events in connection with this research project? ___ Yes __X_ No
If yes, please describe.

4. __X__ This is a request for renewal of ethics approval.

5. ___ This project is no longer active and ethics approval is no longer required.

6. List all current funding sources for this project and the corresponding project titles if not exactly the same as the project title above. Indicate the Principal Investigator of the award if not yourself.

SSHRC CGS Fellowship – no project title given in award application

Principal Investigator Signature: [signature] Date: January 24 2007

Faculty Supervisor Signature: [signature] Date: 29/01/07
(for student PI)

For Administrative Use	REB: ___AGR ___EDU ✓ REB-I ___REB-II
___ The closing report of this terminated project has been reviewed and accepted	
✓ The continuing review for this project has been reviewed and approved	
✓ Expedited Review ___ Full Review	
Signature of REB Chair or designate: Lynda McNeil	Date: Feb 1, 2007
Approval Period: March 17, 2007 to March 16, 2008	

Submit to Lynda McNeil, Research Ethics Officer, James Administration Bldg., rm 419, fax: 398-4644 tel:398-6831

(version October 2002)

Due: March 16 2007