Development-Driven Regeneration of Tropical Forests

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1.0 Introduction

Since 1800, many Western countries have undergone 'forest transitions' (1-3), i.e., shifts from deforestation to forest regeneration driven by 'developmental' trends (2, 4-6). Since 1990, regeneration has also featured in certain tropical countries (7-14). The purposeful continuation of trends driving tropical regeneration might further restore tropical forest cover and prevent deforestation. Forest transitions (FTs) are thus a potentially attractive source of 'easy' carbon credits within the REDD (Reduced Emissions for Deforestation and Forest Degradation) scheme of the United Nations Framework Convention on Climate Change (UNFCCC) (15).

FT theory suggests various 'pathways' of social change and regeneration. Yet data and methodological limitations have precluded detailed descriptions of the FT in tropical countries, such that policy has been unable to promote a FT. Critical questions remain unanswered: (*i*) What are the principal pathways of the tropical FT? (*ii*) How strong is the relationship between socio-economic development and regeneration? and (*iii)* Might the relevant socio-economic trends be harnessed to promote a FT, as within REDD?

In the context of Panama, I address these questions. I do so by integrating full-count microdata (i.e., respondent-level census data) for 1980-1990-2000 with satellite imagery for 1990-2000-2008, for 82% of counties (*corregimientos*) not exclusively urban in 1980, to thus observe the long-term, parallel trajectories of socio-economic, agricultural and forest-cover change culminating in forest regeneration.

The following section summarizes the pathways of the FT according to the literature. Section 3 summarizes the shortcomings of their empirical definition to date. Section 4 concerns the methodology. Section 5 details the FT in Panama according to my own model, and section 6 concludes. I emphasise here that the following is a highly simplified version of the original manuscript.

2.0 Pathways Past and Present

FT theory derives from qualitative accounts of change in Europe and North America during the 19th and 20th centuries. The main narrative is that population concentration and industrial growth spurred agricultural intensification and rural-urban migration (6), in turn encouraging the abandonment of marginal agricultural lands (2), urbanization, and shifts from wood fuel to fossil fuels (1). This reduced pressure on forests and encouraged regeneration and reforestation in marginal areas.

The pathways of tropical regeneration reflect these Eurocentric processes (16) but are also more varied. Four major pathways are discussed below (5, 17). These overlap in practice, but also tend to predominant in different contexts.

(*i*) URBAN-ECONOMIC GROWTH: This pathway maintains that urban-economic growth may draw labour and investment away from agriculture, reducing the viability of marginal agriculture and increasing rates of land abandonment and attendant forest regeneration. This is considered most likely if coincident agricultural intensification depresses the prices of agricultural commodities. Despite the prominence of this narrative, it has limited evidence. Most empirical tests are highly spatially aggregate (usually cross-national), use simplistic social measures (e.g., GDP/capita, % urban population), and presume that developing and developed countries sit on a *common* trajectory of change (4, 5). (18) (8), (19).

(*ii*) FOREST SCARCITY: This pathway describes demand-driven reforestation in forest-scarce contexts where declining ecosystem services and/or increasing demand for forest products increase the value of forest cover (5) (20). Landholders respond by promoting regeneration for environmental services and/or reforesting for commercial gain (20, 21) personal use (22: 86-7) or other (23). This pathway may overlap with that of urban-economic growth, given urban demand for forest products (24) (19).

(*iii*) GLOBALIZATION, MIGRATION AND NON-FARM ACTIVITY: This pathway holds that globalization may prepare the way for regeneration by reducing economic viability in certain rural areas (25), as via cheap imports of grain (26), foreign agro-enterprises that outcompete peasant producers (27), resource depletion (28, 29), or similar. Key is that rural emigration of poor smallholders searching for wages depletes the labour of agriculture households, yielding an economically-depressed, semi-abandoned, semi-regenerating landscape (9: Ch3). El Salvador provides an example (10, 30). This pathway is differentiated from that of urban economic growth by its focus on migration and rural income diversification.

(*iv*) STATE-LED REFORESTATION: This pathway is one whereby state action facilitates reforestation and regeneration independent of forest scarcity or economic development (17: 109), as for example to 'green' a national image. I re-define it here as the more common scenario whereby a strong state spurs regeneration/reforestation along lines described previously, whereas otherwise this might not have occurred (to the same extent). As state action is so varied, no archetypal pathway exists. However, the regeneration and reforestation following Vietnam's *Doi Moi* economic liberalization is illustrative (13: 182-5, 17: 113-6, 31). The 'strong state' has played a significant and role in Asian FTs (32, 33).

3.0 Modelling the Tropical Forest Transition

Empirical models of the tropical FT have failed to describe its nature with a level of detail meaningful to theory or policy. Hereafter 'model' refers to regional-to-national-scale regression models of forest-cover change as a function of social change, as these have been used almost exclusively to describe the tropical FT. All have adopted the same approach of integrating published time-series census data with satellite estimates of forest regeneration. As such, all share similar shortcomings, summarised below.

3.1 Inappropriate Methods

Models string narrowly-defined variables into a single regression expression thus:

$$\textit{Forest-cover change} = \alpha + b_1 \textit{Variable}_1 + b_2 \textit{Variable}_2 + \ldots\, b_k \textit{Variable}_k$$

Most models incorporate far too few variables to define the multiple facets of a pathway (4, 12, 34, 35). More seriously, a models is interpreted as a *single, integral* pathway of regeneration (e.g., 8); yet it is unlikely that but one pathway exists in a given context. Thus, folding all social trends (i.e., variables) into a single expression yields a 'forced' pathway that is as much a statistical artefact as an illustration of reality. Consider that, in regression modelling, the explanatory terms are not collinear. Instead, they represent relatively mutually-exclusive phenomena unlikely to significantly co-vary in space and time and, thus, to form an *integral* pathways of change. Consequently, the explanatory power of a model (i.e., R^2) is probably inflated as a statistical artefact.

Models rarely observe the strength of actual relationships between regeneration and its driving social trends. Instead, they merely establish the *statistical* significance of a 'driver', i.e., that its effect is not nil. Even if statistical significance equates with a strong relationship, given the paucity of data with which drivers are defined it remains completely unknown whether a given driver is *truly* important and not merely deemed so because it stands in for other, unobserved trends (e.g., 36: Ch5).

3.2 Poor Data

All models necessarily observe change at some aggregated spatial unit, e.g., the district, the municipality, etc. In published censuses for tropical countries, these units are often appreciably aggregated, spanning hundreds if not thousands of km^2 each (10, 12, 33, 37, 38). At such scales, correlations are only somewhat meaningful. Spatial aggregation inflates correlations (39: esp. 27-30). Ecological fallacies are problematic even at moderate levels of aggregation, and interact with the Modifiable Aerial Unit Problem in proportion with aggregation, adding further uncertainty to interpretations (39) . The likelihood of inflated correlations is compounded by the small number of variables in most models. Further, regeneration usually concentrates within relatively few units of observation (12, 38), which are indeed few due to spatial aggregation, all of which has negative implications for model reliability and robustness. For all these reasons, relationships deemed to be significant aspects of the tropical FT may, in fact, be otherwise.

Short periods of observation mean that models capture only brief snapshots of the pathways of the FT. The poor availability of time-series data at fine scales in published censuses mean that virtually all models describe social and forest-cover change over a single period spanning ~10 years, and sometimes less (9, 12, 13, 37, 38). Such brief periods inhibit the consideration of trends preceding regeneration, the 'unfolding' of economic development, the time lag between social change and forest regeneration, and so on. This is all the more true given that the pathways of tropical regeneration may very well trace a curvilinear track.

Summarising Section 3, an improved model of the tropical FT should ideally: (*i*) make observations over multiple consecutive time periods, spanning *at least* twenty years, both before and after regeneration; (*ii*) incorporate *many* variables to define *multiple*, complex pathways of change; (*iii*) have national coverage, but also a *fine* spatial resolution; (*iv*) reveal the *actual* strength/importance of the drivers of regeneration; (*v*) consider spatial-statistical dependence between units of observation. The following analysis for Panama addresses all but the final criterion.

4.0 Methods

A canonical correlation analysis (CCA) determined two pathways of social and forest-cover change as two pairs of linear combinations having maximum correlations. Each pair considers two satellite-derived estimates of forest-cover change (1990-2000-2008) alongside eight dimension of socio-agrarian change (1980-1990-2000). The eight dimensions are similarly linear combinations (principal components) of 39 social, economic and agrarian trends, and describe the major socio-agrarian transformations in Panama since 1980. In this way, the CCA consolidated more than 40 trends over three decades into two overarching pathways of socio-environmental change. Pathways are defined as overarching 'macro' trends encompassing lesser trends 'hanging together' in space and time. They are trends upon trends, acknowledging the interplay between trends' historical inertia and their propensity to evolve as they alter their underlying conditions.

4.1 Census Microdata (Socio-Agrarian Trends)

Full-count census microdata for Panama's population and agricultural censuses of 1980, 1990, and 2000 defined 39 social, economic and agrarian trends over 1980-1990-2000. Microdata were first aggregated to the county (*corregimiento*) scale, as defined in 1980, where the county is the smallest administrative unit amenable to national-scale time-series analysis. Where a county was sub-divided after 1980, its 'children' counties were merged to reconstitute the original 'parent' county, as delimited in census maps, thus maintaining consistent units of analysis. Of 505 year-1980 counties, I retained 388 having (*i*) ≥ 25 farms and ≥ 100 persons, thresholds which guard against spurious proportional measures (most trends are expressed as 'proportion of some base, such as total population, county area, etc.), and (*ii*) rural populations, pasture and rice cultivation, over 1980-2000. 'Special Areas' – defined as having difficult access, and often predominantly indigenous populations – were omitted, as agricultural censuses solicited only basic data therein. The spatial dimensions in km^2 of our 388 counties are: mean 118, std. dev. 237, median 64, min 3, max 3512. A parallel principal component analysis (40, 41) of the 39 variables defined our eight dimensions of socio-agrarian change.

4.2 Satellite Data (Forest-Cover Trends)

Satellite-derived maps of forest cover in 1990, 2000 and 2008 (42, 43) provided our forest data. The 2008 map derived from ASTER imagery with 16 m pixel resolution, ~90% accuracy for 16 classes, and a minimal mappable area (MMA) of 4.5 ha. The 1990 and 2000 maps derived from Landsat imagery having 30 m resolution and an unquantified but "very low margin of error" (42: 27) for the same classes. No MMA is specified, though "excessively small" (42: 27) areas were reclassed as neighbouring land covers, and few polygons <4.5 ha exist. For all maps, all forest classes save plantation, mangrove and early regrowth ~5 years old were collapsed into a general forest class for analysis. Forest-cover change is defined per county as the change in forest area as a proportion of year-1980 county area, per decade.

5.0 Results: Pathways of Regeneration in Panama

The principal components analysis (PCA) of 39 social and agrarian trends over 1980-1990-2000 yields eight major dimensions of socio-agrarian change with which I characterize pathways of regeneration in Panama: DIMENSION 1 - rural affluence; DIMENSION 2 - urbanization and peri-urban density (esp. 1990s); DIMENSION 3 - ranch expansion (1980s) and agro-economic bust (1990s); DIMENSION 4 - forest-pasture conversion (1980s) and pasture-forest conversion (1990s) on farm; DIMENSION 5 - deagriculturization of labour force alongside increased female labour-force participation and income, with forest scarcity (esp. 1990s);

DIMENSION 6 - deagriculturization of labour force alongside increased female labour-force participation (1980s); DIMENSION 7 - declining rural population density with 1980s urbanization; DIMENSION 8 - rise and fall of corporate agricultural extent, with overall agricultural contraction in 1990s. The eight dimensions explain 51% of the variation amongst counties, this being considered appreciable given the very high degree of variability in the dataset.

Two pathways of regeneration surface as canonical correlations between the socio-agrarian dimensions and satellite observations of forest-cover change (Table 1). In Table 1, a pair of canonical variates (Y1 & X1, or Y2 & X2) represents a single pathway. The first (Y1 & X1), termed *Rural Ascendency*, observes deforestation over the 1990s then regeneration over the 2000s alongside expanding agricultural activity over the 1980s (-Dimension 6) and rural affluence over the 1990s (Dimensions 1 & 2). The second (Y2 & X2), termed *Economic Ascendency*, observes sustained regeneration over 1990-2000-2008 alongside sustained declines in agricultural employment and increases in female employment (Dimension 5 & 6), improving rural economic well-being in the 1990s (Dimensions 3 & 5), and a boom-and-bust trend in corporate agriculture that also entailed overall agricultural contraction (Dimension 8). The canonical correlations appear moderate, at 0.34 and 0.28 respectively (Table 1). However, in considering that the correlations are highly significant ($p<0.001$) despite the marked diversity and the fine scale of the 388 counties, they are more appreciable than would first appear. (Note: Unlike simple correlations, canonical correlations cannot be squared to yield a 'R^2' measure of 'percent variance explained').

The Rural Ascendency pathway depicts a 'turning point' whereby regeneration overtook deforestation. Increased agricultural activity over the 1980s echoed deforestation into the 1990s, and while rural affluence during the 1990s may have contributed to, or at least coincided with, this deforestation, it also facilitated regeneration over the 2000s (Table 1). Rural affluence entailed a high and gradually increasing proportion of farm households reliant on non-farm income over the 1990s, as well as high rural incomes and female-employment rates in 1980 and 1990, the later a proxy for labour-market demand and service-sector orientation. Rural populations fitting this description had long straddled agricultural and non-agricultural economic activities, and increasingly favoured the later by 2000. Hence, for a subset of counties *archetypal* of this pathway, being counties scoring a relatively high ≥+0.75 standard deviations on variates Y1 & X1 in

Table 1: Canonical Correlations of Socio-Agrarian and Forest-Cover Change, 1980-2008

Forest-Cover Change			Socio-Agrarian Change		
Variable	*Variate Y1*	*Variate Y2*	*Variable*	*Variate X1*	*Variate X2*
CANONICAL LOADINGS					
Forest Change 1990s	-.909	.424	Dimension 1	.733	.192
Forest Change 2000s	.606	.796	Dimension 2	-.471	.017
			Dimension 3	-.035	-.456
			Dimension 4	-.104	.322
			Dimension 5	.229	.521
			Dimension 6	-.399	.466
			Dimension 7	.048	.014
			Dimension 8	-.120	.404
STANDARDIZED CANONICAL COEFFICIENTS					
Forest Change 1990s	-.814	.620	Dimension 1	.733	.192
Forest Change 2000s	.434	.927	Dimension 2	-.471	.017
			Dimension 3	-.035	-.456
			Dimension 4	-.104	.322
			Dimension 5	.229	.521
			Dimension 6	-.399	.466
			Dimension 7	.048	.014
			Dimension 8	-.120	.404
% Variance Explained	59.4	40.6		12.5	12.5
Correlation: Y1 and X1	R =.34	Wilk's Test = .819 ($p<0.001$, χ^2 =76.21, df.16)			
Correlation: Y2 and X2	R= .28	Wilk's Test = .923 ($p<0.001$, χ^2 = 30.66, df.7)			
N	388 counties				

Table 1 (n=17), I observe over the 1990s declining agricultural populations and declining rural male unemployment simultaneous to increasing rural populations and rural incomes. The same pattern is observed for counties *exemplary* of Dimension 1, these counties scoring a less stringent and therefore more inclusive ≥+0.5 standard deviations on the dimension (n=118). Indeed, in a selection of counties *exemplary* of the pathway (i.e., ≥+0.5 std. dev. on variates Y1 & X1) (n=47), a regression analysis illustrates that 33% of the decline in farm households totally dependent on farming for sustenance is explained by the increase in mixed-livelihood households and the decline in persons employed in agriculture over the 1990s. Thus, prior to the regeneration of the 2000s, the population of the Rural Ascendency pathway was historically and increasingly integrated with a prosperous non-farm economy. To the extent this integration reduced agricultural activities by diverting labour off-farm, it heralded subsequent regeneration.

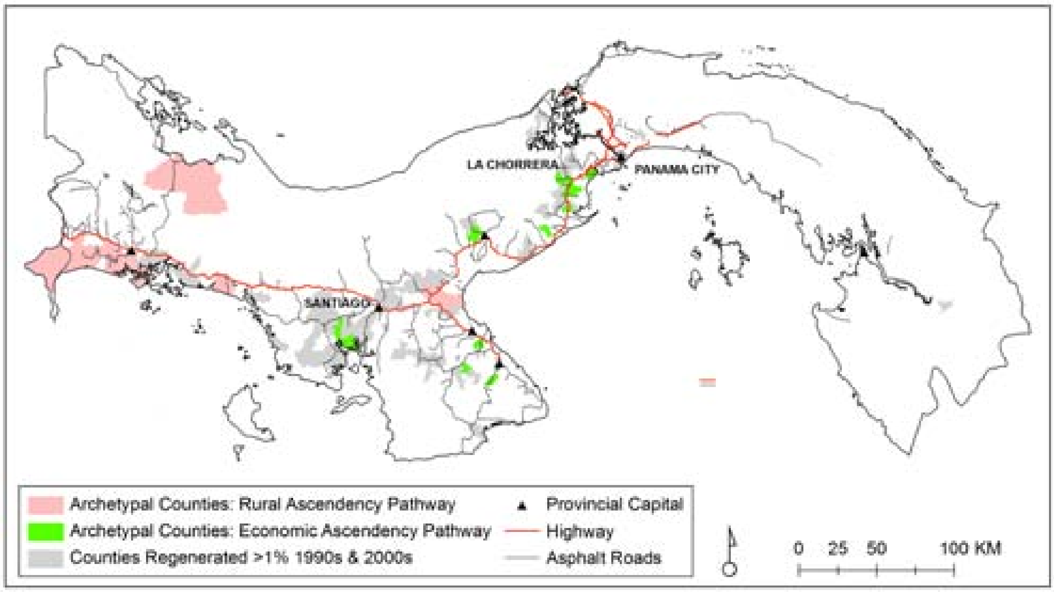
The Economic Ascendency pathway more explicitly ties regeneration to a growing non-farm labour market. Sustained regeneration tracked sustained decreases in agricultural-employment rates and sustained increases in female-employment rates (Table 1). These two labour trends are strongly inversely correlated and indicate multiplying alternatives to agricultural livelihoods: opportunities for female/service-sector employment, which are largely non-agriculture, increased in step with decreasing agricultural-employment rates over the 1980s and 1990s. Agricultural-employment rates declined as farmers were similarly incorporated into the growing non-farm labour force. Hence, as above, in counties *archetypal* of this second pathway (n=13), rural populations increased coincidently with decreasing agricultural employment, decreasing rural male unemployment, increasing rural incomes and, ultimately, an accelerating contraction of agricultural extent.

The corporatization of agriculture appears related to the nexus of regeneration, economic growth, deagriculturalization, and agricultural contraction. In the Economic Ascendency pathway, corporate agricultural expansion over the 1980s accompanied deagriculturalization. Continued deagriculturalization into the 1990s then precipitated the contraction of corporate and total agricultural extent, at which point regeneration commenced (Table 1). Agro-corporatization also featured in the Rural Ascendency pathway, though as it commenced later (1990s) there is a poorer record of its role. In this pathway, despite deagriculturalization over the 1990s, agricultural income grew strongly as a proportion of total income. Corporate agricultural extent also grew over the 1990s in 70% of the 17 counties *archetypal* of this pathway, 66% of the 118 counties *exemplary* of Dimension 1, and 50% of the 47 counties *exemplary* of this pathway, again coincidently with deagriculturalization. Only subsequently (2000s) was regeneration observed. It would however be incautious to claim that agri-corporatization *caused* deagriculturaliation and regeneration; simple correlations of these trends are weak. What can be said is that agri-corporatization consistently preceded these trends. Rather than a cause or effect, corporatization is more an *aspect* of the very phenomenon to which deagriculturalization and regeneration belong, *analogous to pillars of a single edifice*. If the drivers of corporate agriculture encouraged agricultural households to reallocate labour off farm, a strong non-farm labour market availed itself to receive it.

Regenerating counties are decidedly not marginal. Counties *archetypal* of either pathway or otherwise experiencing sustained regeneration clustered systematically along the Pan-American Highway near provincial capital cities (Figure 1). Such locations are economically advantageous. Not coincidentally, they are also where rural population density is greatest, forest scarcity acute, and peasant agricultural expansion and deforestation most pronounced over 1940-1980 (44). Indeed, there is a very strong spatial agreement between, on the one hand, the confluence of the highway with areas of high soil fertility and the Pacific dry forest biome – i.e., the historic cradle of Panama's settlement (12: Fig.1) – and on the other hand those counties *exemplary* of the *social transformations* of the Economic Ascendency pathway (≥+0.5 std. dev. on variate X2) or of both pathways combined (≥+0.5 std. dev. on variates X1 & X2). Economically favourable locations appear integral to the pathways. In the case of the Economic Ascendency pathway, whose *archetypal* counties cluster around the circa-1980s deforestation frontier of the western Canal Zone (Figure 1), the widening of the highway from Panama City to La Chorrera over the 1980s spurred early investment in resort and 'dormitory' communities. This investment greatly increased demand for service sector workers, thus initiating its deagriculturalization. Similarly, the widening of the highway to Santiago over the 1990s was likewise accompanied by sustained regeneration (Figure 1)

As much of the interest in the FT stems from the possibility that it might restore tropical forest depleted by decades of deforestation (45), it is appropriate to consider the area regenerated. This analysis indicates that the absolute area of regeneration is appreciable, but still dwarfed by deforestation elsewhere. Amongst the 135 counties (7,603 km^2) *exemplary* of the social transformations of the Economic Ascendency pathway,

Figure 1: Regenerating Counties and Those Archetypal of the Pathways of Regeneration



net forest-cover change over 1990-2008 was +312 km^2, or +4.1% of the total area. Similarly, amongst the 43 counties (2,485 km^2) *exemplary* of the social transformations of both pathways, net change was +72 km^2 or +2.9% of the total area, a lesser rate owing to the deforestation inherent to the Rural Ascendency pathway (Table 1). Thus, over 1990-2008, net forest gains per decade were approximately 1.5-2% of the area of influence of a given social dynamic. These regeneration rates are comparable to per-decade deforestation rates since 2000, at 1.5% of the *national* area, but minor relative to earlier rates of 8% (1980s) and 5% (1990s) of the national area[1] (46-48).

6.0 Conclusion

Panama's FT was one whereby a confluence of events, each following from the preceding, readied the way for an employment shift that followed though to a forest turnaround point. Decades of agricultural settlement, infrastructural development, population densification and labour-market diversification in Panama's interior culminated in favourably-situated urban hamlets in rural landscapes. The urban hamlets hosted employment shifts tending to replace, rather than displace, agricultural labour. The FT centred on deagriculturalization and *in situ* economic development, of which agricultural change appeared but symptomatic.

The complexity of the FT cautions government against attempting to 'cause' one. A more feasible approach is to nurture a FT once already underway or nearly so. The most practicable and effective way to do so within the REDD scheme is early in a phased implementation of REDD policy(49), this having been supported by the UNFCCC (50: Para.73). Amongst 'REDD- ready' countries having passed Phase I (i.e., development of REDD strategy), Phase II would reward policy, reforms and investments likely to nurture the FT but whose marginal effect on regeneration need not be quantified. Candidate reforms might include infrastructure upgrades, regionally-targeted tax exemptions and subsidies for job creation, and 'payment for environmental services' to regenerate farms and divert rural labour off-farm. As the effects of sustained efforts of this kind grow alongside a country's capacity to monitor its forests, the country graduates to full REDD compliance (Phase III), at which point a carbon market rewards subsequent net gains (or avoided losses) of forest carbon. Ideally, FT investments would begin to bear fruit not long after the commencement of Phase III. If realized, such an endeavour could provide a growing, long-term and perhaps self-maintaining stream of carbon-credit payments. Given that nascent FTs are already underway in **Vietnam, Panama, South-Eastern Brazil, Costa Rica, El Salvador, and Puerto Rico** and elsewhere, there is reason for such countries to seriously consider a nurtured FT as part of their REDD strategy.

[1] National per-decade deforestation rates calculated as (Annual Area Deforested × 10 years) / Area of Panama × 100%.

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