Ambiente & Sociedade
ISSN: 1414-753X
revista@nepam.unicamp.br
Associação Nacional de Pós-Graduação e
Pesquisa em Ambiente e Sociedade
Brasil

THE DEVELOPMENTAL CYCLE OF DOMESTIC GROUPS AND AMAZONIAN DEFORESTATION

EMILIO MORAN*
STEPHEN MCCRACKEN**

I. INTRODUCTION

Only a few years ago, Anne Pebley noted that "empirical research [by demographers] on environmental issues remains remarkably thin" (PEBLEY, 1998:378). Even then, however, she went on to note that environmental issues had begun to receive more attention from demographers, and proceeded to highlight some of the progress made. There had been macro-decomposition models of greenhouse gas emissions (BONGAARTS, 1992; BIRDSALL, 1992; PRESTON, 1996); county-level studies of the determinants of air pollution emissions (CRAMER, 1998a); studies in industrialized countries of the distribution of environmental hazards and human migration (ANDERTON et al. 1994); and studies of land use and deforestation (BILSBORROW & DELARGY, 1991; PALLONI, 1994; RINDFUSS, WALSH & ENTWISTLE, 1996). Of the above, arguably the area that has made the most progress has been the study of land use and deforestation. Several studies of land use and deforestation have integrated census data, with village survey data, and in a number of cases made use of satellite data to provide a better understanding of landscape features and environmental parameters (ENTWISTLE ET AL. 1998; WALSH ET AL.1999; MCCRACKEN ET AL. 1999; MORAN & MCCRACKEN 2001; WOOD & SKOLE, 1998; PERZ, 2000). The amount and sophistication of work on population and environment has increased rapidly in the past decade.[1]

Older studies examining the causes of deforestation often neglected the dynamic interactions between the human population and the environment. Deforestation is a process mediated by human interventions, from the act of clearing

* Anthropological Center for Training and Research on Global Environmental Change (ACT) and CIPEC, Indiana University, Indiana, USA.
** Researcher at the DRH-NCCDPHP-Atlanta, GA, USA.
Received in 28/08/2004 – Accepted in 17/09/2004.

(e.g. choosing the size of the area cleared, the timing of the burn, whether to remove biomass or not before burning) to how such a clearing is used and managed over time. This is a process whose dynamics cannot be adequately understood solely by looking at aggregate population changes, or even by examining them through census data at municipal scale. To get at the process of how households in a population make deforestation and other land-use decisions requires us to examine total population, cohorts within that population, and the structure of households. Household structure is a likely implicated factor of recent rapid increases in rates of deforestation, rather than natural increase or total population in rural areas. Deforestation for the past 20 years has increased rapidly, alongside a precipitous fertility decline in Brazil over that same period. Brazil's fertility is now approximating that of developed industrialized countries [1.7 births per woman in Brazil as compared with 1.5 for Europe]. In the Amazon frontier fertility rates are higher but the trajectory of decline is comparable in its downward trajectory.

The literature suggests that occupation of a new frontier by a human population leads to distinctive demographic patterns in fertility, mortality and morbidity. Because of the demands for labor in the frontier, fertility is expected to increase; because of the unfamiliarity of migrants with a new environment, higher than expected morbidity and mortality results (MORAN, 1981; SMITH, 1982). Migrant households historically have been younger than the general population resulting in higher wages due to labor scarcity in the first decade of settlement. The relationship between population and the environment is not a direct one. Rather, it is mediated by many other factors such as the land tenure system in place, economic and environmental uncertainties, the limitations posed by a particular age and gender household structure on the labor and capital available, and the past experience of household members in such a habitat.

From the point of view of theory and method, it is necessary to develop new approaches that effectively link demographic process to the interactive relationship of population to specific aspects of an environmental matrix . This paper documents an approach to do so that links traditional household demographic surveys to time-series analysis of remotely sensed data within a spatially-explicit framework made possible by geographic information systems. Geographic information systems (GIS) are tools in the definition, and analysis of complex social and environmental units at various scales that have only recently advanced beyond the map-making stage at which it remained during its developmental period. GIS techniques can be used to define landscape units that have a real physical reality. They can also be treated as products of the ways the inhabitants have acted to shape the economic uses of those natural resources. Thus, landscapes embody a historical tradition of land use, the demographic trajectory of the population that occupies and uses the area, and the changing dynamics of population in the environment (CRUMLEY, 1994). This study examines one such landscape, formed by the arrival of settlers in 1970, brought there, or encouraged to come, by a government bent on occupying the vast Amazon. Their use of resources for the past 26 years is a product of their past experience, of their initial demographic composition, of their initial capital, and of their decisions--both demographic and economic-- that have changed that physical environment into a distinctive human landscape.

Figure 1, "Altamira region in Brazilian Amazon"

This study is based upon a household survey of 402 households in the Altamira region, of the Lower Xingu Basin, Brazilian Amazon, and on analysis of Landsat satellite digital data and ancillary environmental data. (See Figure 1 for location) The area was the object of a planned settlement scheme that began in 1971, associated with road construction, provisioning of credit, and systematic efforts to attract immigrants. The area became a showcase for the potential of the Amazon for intensive cultivation because the soils in this region were reputedly of above average fertility and agro-pastoral economy has grown at a brisk pace for two decades following the construction of the Transamazon Highway. The region has been studied from the beginning of settlement in 1971 by a number of investigators (MORAN, 1981; SMITH, 1982; FEARNSIDE, 1983). None of these earlier investigations examined the structure of households as it relates to land use or theenvironment. Moran (1981) collected demographic data in a number of settlements and noted the unusual age/gender pyramid of these communities during the first years of settlement. The number of dependents was higher than normal for a frontier area at the outset (55% of the population was under age 15 but only 2.4% was over 50) due to the intervention of the government in promoting settlement and the subsidizing of older households to accelerate the occupation of the area. This distortion in the age of household heads was not long lived, after which time the migration pattern became more typical with many migrants being relatively young (20-35) and having fewer and younger children. (See Figure 2 a and 2 b)

Figure 2a "Age & Sex Pyramid: HHs Arriving Before 1976"

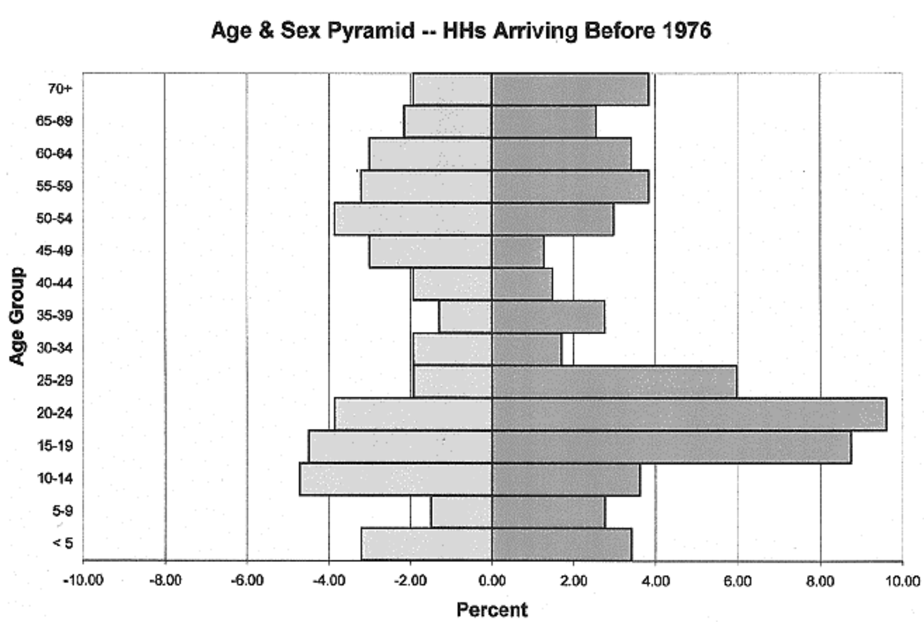
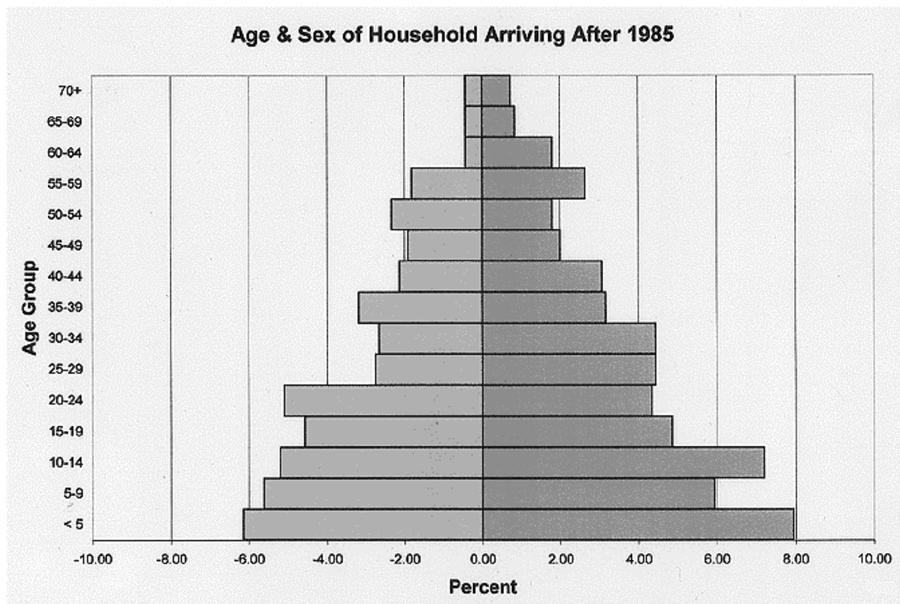


Figure 2b "Age & Sex of Household Arriving After 1985".



This paper hypothesized that younger households arriving at the frontier with a small number of young children will follow a land use pattern characterized by greater rates of deforestation and cultivation of annual crops. As these households age, we hypothesize that the amount of labor available within the household will increase, that children will add substantively to available labor, thereby freeing adults to diversify their economic activities and the taking of greater risks. This will be reflected in a shift towards long-term cropping patterns. The natural growth of this cohort will stabilize as these families achieve their target family size. As these households age further and enter late middle age, land use will be characterized by smaller areas for annual crops, the increasing use of previously cleared land now rather than clearing of mature forest, and increasing total acreage in permanent crops, agro-forestry, beef cattle grazing, logging, and fruit tree production. The magnitude of these shifts will be affected by period effects, reflecting the influence of the political economy, in the form of commodity prices, availability of credit, and opportunity costs on the trajectory of deforestation and land use over time.

II. POPULATION AND ENVIRONMENT

Research on population and environment has been on the increase (PEBLEY, 1998). Studies have examined contextual variables such as the role of social ties, social capital, village infrastructure, wages, and the availability of services

(ENTWISTLE, RINDFUSS & GUILKEY, 1996; PEBLEY, GOLDMAN & RODRIGUES 1996a). Pebley (1998:385) notes that it is time to move from the current focus on the socioeconomic context of human behavior to examine its physical context. In this study, the authors have examined a sizable landscape (3,874 square kilometers) with particular attention to soil quality and types of vegetation; the micro- and macro-economic contextual variables; and the demography of households in an effort to overcome the limitations of macro-simulation and projection models, and of village case studies that represent too small an area. This study is also part of a much larger on-going project at the Center for the Study of Institutions, Population, and Environmental Change in which studies linking population and environment across a large number of sites is being undertaken (see www.cipec.org for complete lists of publications from the Center).

Landscape changes in the Brazilian Amazon frontier, and especially deforestation, are not a simple function of immigration-driven population growth (GILLIS & REPETTO, 1988). Rather, this study shows that the patterns of land use and deforestation reflect the demographic structure of households and the impact of credit policies and other macro-economic forces upon those households. Such a view has been rarely the focus of research in the tropics, where much of the literature blames the smallholder for the destruction of forest (MYERS, 1984) or finds the political economy within which he is located as responsible for driving households to the frontier (SCHMINK & WOOD, 1992). The literature has given much less attention to the internal logic of, and demands upon, households through time as they make land-use decisions (TURNER et al. 1994). While the political economy is certainly part of the story, our analysis focuses on the trajectories of households at a micro-demographic and land-use level, and on the methodology for locating these processes within a regional landscape so that understanding of these processes is not limited by traditional approaches to household analysis.

The Brazilian Amazon is a region of particular significance for a study such as this on both environmental and demographic grounds. The Brazilian portion of the Amazon accounts for well over two thirds of the Basin in spatial terms (ca. 4 million square kilometers), and its population reached 8,892,000 in the 1990 census (IBGE 1991). The only other detailed study of the demography of an Amazonian region is that of Pichon & Bilsborrow (1992) in a pioneer front of the Ecuadorian Amazon, from whose findings and recommendations, we have derived considerable inspiration for this project (see also PICHON & UQUILLAS, 1997; PICHON, 1997; 1996).

The results of road-building, farming, ranching, and logging have been devastating to the tropical forests of the Brazilian Amazon (FEARNSIDE, 1983, 1987; BROWDER, 1988; MAHAR, 1988; UHL & VIEIRA, 1989). Little deforestation had occurred in Brazil's Amazon before the 1970s. As of 1975, only 30,000 square kilometers or about 0.6% of Amazonia had been cleared. Since 1975 the rate of deforestation has steadily accelerated with a four-fold increase to 125,000 square kilometers by 1980, and twenty-fold to 600,000 square kilometers by 1988 (MAHAR, 1988). Both Booth

(1989) and Setzer & Pereira (1991) reported that up to 8 million hectares of forest were burned in 1987. Rates have declined by half between 1989 and 1993 as a result of economic recession in Brazil, which affected also the rates of immigration and of external investments. Following the stabilization of the currency in 1994, there was a notable increase in deforestation in 1995, followed by a modest decline. It remains at relatively high levels today (i.e. above 0.5% of the Basin per year). This rate is lower than that in other countries, such as Ecuador, that have much smaller areas of their total territory in the Amazon but the absolute amounts are staggering (i.e. the total area deforested in the Brazilian Amazon in the past 20 years is equivalent to the total land area of Spain, Portugal and France). Because so much of the Brazilian Amazon has remained hard to reach due to poor road infrastructure, much of it remains relatively unaffected by deforestation. Rates in colonization fronts served by passable roads, as we will see, tend to be considerably higher- i.e. 1% to 6% per year.

Concerns about deforestation have focused on the effects of deforestation on biological diversity (WILSON, 1988), climate change (DICKINSON, 1987; SHUKLA et al. 1990; ABER & MELILLO, 1991), and atmospheric trace gases (DICKINSON 1987; ANDREAE & SCHIMEL, 1989; CRUTZEN & ANDREAE, 1990; DALE et al. 1991). Attention has also been directed to tropical forests' contribution to the global carbon cycle (DETWILER & HALL, 1988). Moist forests of the tropics cover only about 11% of the Earth's land surface but are estimated to contain 41% of the global terrestrial biomass and over 50% of the world's species. The Brazilian Amazon contains 26.5% of the Earth's moist forests (WHITTAKER & LIKENS, 1975; PRANCE & LOVEJOY, 1985; SILVER, 1990). The continental size of the Amazon Basin and its high evapo-transpiration rates make it a notable influence on world climate (SALATI, 1985; MOLION, 1987). Removal of Amazonian vegetation on a large-scale, it is believed, will bring about sufficient changes in the region's hydrological cycle and climate large enough that the forests may not be able to re-establish themselves (SHUKLA et al. 1990; cf. also HENDERSON-SELLERS, 1987; LEAN & WARRILOW, 1989), or will experience significant change in species composition, structure and function.

It is generally taken for granted that the major driving force in deforestation in the tropics, and in the Amazon, is population growth (MYERS, 1984). In the African and Asian tropics it is taken to be high rates of natural increase, and in the Amazon it is assumed to be the high rates of immigration followed by subsequent intergenerational high rates of natural increase (GILLIS & REPETTO, 1988). This study and a recent synthesis (GEIST & LAMBIN, 2001) question this general assumption. Over the past 25 years, the first author and other investigators (MORAN 1981; SMITH 1982; SCHMINK & WOOD 1992; PICHON & BILSBORROW 1992; BRONDIZIO ET AL. 1996; GEIST & LAMBIN, 2001) have observed what appear to be different dynamics. It has been observed that as households age and children leave to form new households, land use shifts from high labor to low labor activities, from opening new land from forest, to managing fallows. In the study area, environmental research on deforestation and re-growth of vegetation suggests that the population are doing twice as much management of fallows than new deforestation after only one decade of rapid clearing (Moran et al. 1994a). The dominant assumption would interpret this as a product of declining population and point to the aggregate high rates of rural to urban migration within the Amazon region for evidence. The hypotheses proposed in this study suggest that environmental changes, such as deforestation, succession, and pastoral activities must be understood as products of the age and gender composition of households and their developmental cycle as they age in the frontier).

In the study area we see properties of 100 hectares with half of the property deforested and in cattle pasture, while a neighboring property of the same size may have deforested only one-fifth as much and has the land in coffee, cocoa, and fruit trees. These differences, we suggest, are largely a product of differences in the structure of households, and in the age and gender composition of its labor pool. We also suggest that initial physical environmental endowments (such as soil quality) affect the decisions made by households. Our view does not dismiss the role of capital but predicts that capital accumulation in most of these households is a product of accumulation taking place as households grow and age. A small percentage of households in the area may have unusually large amounts of initial capital, but our experience suggests that most households are capital-poor within 6 months of arrival due to lack of familiarity with the environment and the high costs of deforestation and land preparation in the early stages of settlement when labor is scarce and wages are high (Moran 1988). This study hopes to contribute methodologically to the study of population-and-environment by developing a set of procedures that link field survey data to high resolution satellite data sets by spatially geo-referencing information so that analyses are able to treat population within a spatial and environmental matrix, not only at a given point in time but across years.

It is important that social scientists undertaking study of the reciprocal relationships between demographic dynamics and environmental change take seriously the forms according to which the environment is organized. While some social scientists have a natural preference for political units such as nation-states, provinces, states, communities and metropolitan areas, others prefer to work at the level of the household, and only rarely does either group delve to any great extent into processes taking place in the physical environment. In fact, because of the way large-scale demographic data is collected, through national censuses, the smallest unit of analysis is commonly the county or municipality--and this is certainly true for Brazil. This corresponds to the lowest level of political administration. Focus on this unit, however, ignores the variability that may be present in the physical environment and how this variability may affect the demographic behavior of households in that area. Environmental variability is not coterminous with political boundaries. Thus, sole reliance upon the census for understanding the mutual relationship of population to the physical environment is bound to be disappointing when addressing population-and-environment questions. Large-scale household demography samples, such as DHS, tend to focus on urban areas and rarely sample isolated rural areas because of the difficulty of survey work in those areas.

The relationship between fertility and land use is of concern to both demographers and environmental scientists. But a recent state-of-knowledge paper revealed a concentration of such studies on Europe, U.S., and Canada--and a notable neglect of such studies in Third World countries. The relationship between fertility and land use is commonly indirectly inferred rather than directly studied. Studies examining land quality and systems of land tenure, as they relate to fertility are rare (NETO, 1992). Two studies in Brazil (but neither on the Amazon) stand out (MERRICK, 1978; ALMEIDA, 1977). Merrick examined the Central-West frontier and the old Parana frontier and found that land availability and access have a positive influence on fertility. Almeida (1977) examined two areas of Northeast Brazil and found that sharecroppers had higher fertility than smallholders or squatters and related this difference to the value of children's labor.

High fertility has been said to be a threat in fragile environments such as Amazonia. High and/or rising fertility suggest increasing pressure on the environment. However, population growth in the Brazilian Amazon appears to have been spurred over the past 20 years more by migration than by high fertility (ALMEIDA, 1992:4). Surprising, too, has been the finding that much of that immigration into Amazonia has ended up in small, medium, and large cities rather than the countryside (BROWDER & GODFREY, 1997). Most of the population in these cities is not land owning (though the few that are tend to own large properties and account for a significant proportion of total deforestation). Throughout the 1970's and 80's, fertility fell throughout all regions and classes in Brazil (WOOD & CARVALHO, 1988). Total fertility fell 21% between 1960 and 1980 censuses, but in 1980 women in the Amazon still had an average of 6 children, as compared to a national average of 4 children (LOVELL, 1994). These high rates of fertility are undoubtedly related to the high rates of infant mortality in the Amazon (roughly 100/1000 live births). In addition, children are important as labor on the farm (Ibid.). These relationships are especially significant in a frontier setting. Recent migrant women have higher infant mortality rates than those who have longer residence in the region. The experience of high infant and child mortality in the Amazon affects the target population size of women. In a study of Machadinho, in the state of Rondônia, a frontier area similar to that of Altamira, found no clear tendency towards high fertility, but rather an increasing use of contraceptive methods, and lower infant mortality rates than are common region-wide (NETO, 1992).

In fact, little is known about fertility in the specific context of the Brazilian Amazon. Frontiers have traditionally had increases in fertility following initial colonization. Increased fertility makes sense in the context of ample lands and highly needed labor. DHS surveyed Brazil with approximately 4,000 women in 1986 (and Northeast Brazil in 1991). Like the National Household Survey of 1984, which also permits estimates of fertility with the use of birth histories, the sample did not include rural areas of the Amazon. Our study addresses issues related to the frontier fertility thesis and evaluates the relationships between fertility behavior and economic strategies in the Amazon. Urbanization processes and downward shifts in fertility in both rural and urban areas are critical variables in understanding how population changes affect the fate of the forest.

There is a need to move away from dependency on census units of demographic analysis and begin to explore how other approaches to defining appropriate units might be derived. One such unit is suggested by advances in ecosystem ecology (MORAN, 1990b). The ecosystem unit of analysis defines a community of interacting biotic and abiotic components which have a definable structure and complementary functions. In recent years ecosystem ecologists have moved towards the use of "landscapes" as units of analysis. This unit may refer, for example, to a watershed, i.e. a section of the physical environment that shares common characteristics but that is far from being homogenous (CRUMLEY, 1994).

It would be all too easy to choose the landscape as the unit of analysis. This research project resisted this temptation, opting instead for a dynamic dialectic between units of analysis at both micro- and meso-scale, between households and landscapes. This presents unique challenges to analysis but it also offers a rare opportunity to understand the behavior of households--which after all must make important decisions each day about labor allocation, fertility, and land-use that are constrained not only by the logic of the domestic group or by the logic of the political economy, but by landscape and national processes that reach down to the heart of each household.

A dilemma of studies of population and environment is the scale at which such a study may be undertaken. A dominant position has been taken in the discourse on this issue by those studying the problem at global and international scale (STERN, DRUCKMAN & YOUNG, 1992; WOOD & CARVALHO, 1988). At this level of aggregation, the culprit in many of the problems we see all around us is categorically affirmed to be the human population's continued and exponential growth at global scale. However, when we shift the scale of analysis from the global to the local and regional, a different set of causes and consequences can be seen. At this micro- and meso-scale of analysis one is able to observe that population increase does not invariably lead to deforestation and to land degradation. One finds these outcomes in growing, declining and stationary populations. Declining populations may increase their consumption of natural resources and bring about larger impacts on environment than growing populations with stationary or declining consumption patterns. Stationary populations may reduce the areas they harvest natural resources from, while intensifying their management of those smaller areas so that their total impact on the landscape is a beneficent one. In short, the human causes of environmental change at this scale are complex, indirect, and interactive. In such a complex local and regional landscape how might one begin to understand the interactions?

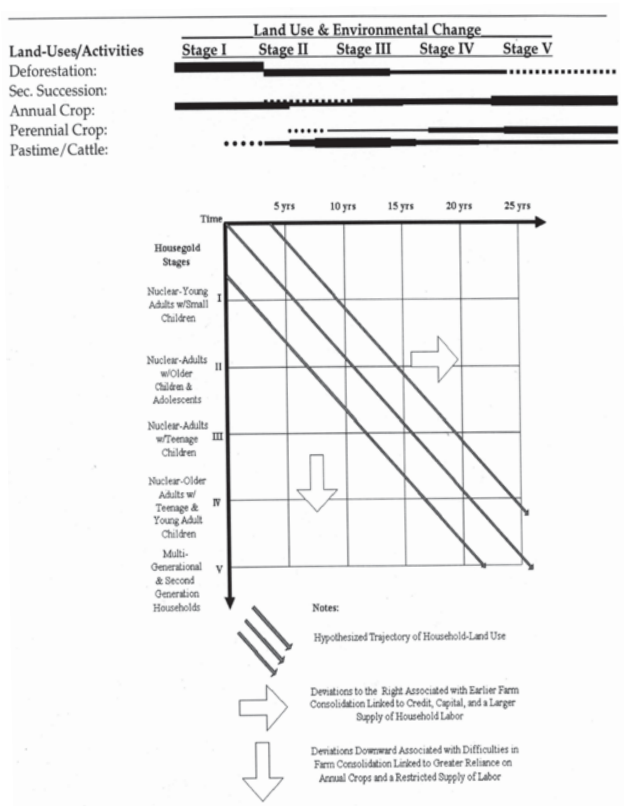
While we have proposed above the value of focusing on the landscape unit of analysis, this study's strength is not to focus on it exclusively, nor on households exclusively, but to give priority to the analysis of the interactions and linkages between these two levels of analysis as made concrete in space and time by changes in physical characteristics of the landscape and changes in the age and gender composition of households. Households have their own internal dynamic and logic which reflects differences in age and gender, in occupation, and in decisions about the use of wealth (NETTING et al. 1984). But these decisions are not unconstrained. Each household operates within a larger entity which we call a landscape or region, where it competes with other households for resources, creates alliances (both economic and marital), and where it seeks to allocate its labor to the benefit of members of the household. This study is well aware that household members differ in their goals and strategies. Households operate according to their own logic, but this logic may not necessarily recognize the impact of their actions upon the physical environment--at least not at first. At this more inclusive scale, the signals from the physical environment to households may be masked, or communicated, by indirect signals such as declining yields, increased periodicity in rainfall, or increased infant mortality (MORAN, 1979). This landscape or meso-scale of analysis, in turn, is nested in more inclusive levels of analysis such as the province and nation--where demographic processes may be recorded but be devoid of environmental connectedness and behavioral determinants (MORAN, 1981).

III. THE DEVELOPMENTAL CYCLE OF HOUSEHOLDS: A CONCEPTUAL MODEL

The development cycle of households as presented by Jack Goody (1976) provides a useful conceptual model for thinking about temporal processes experienced by domestic groups. The development factor is intrinsic to domestic organization and to ignore it is to misinterpret and misrepresent the differences present in nuclear, extended, and multigenerational domestic groups. The alignments of residence of domestic groups represent less the relationships of kinship and family than they do the economic, affective, and jural relations that spring from these factors. The composition of the nuclear family and the domestic group may be identical, as it generally is in our own society. "One might put it that the domestic domain is the system of social relations through which the reproductive nucleus is integrated with the environment and with the structure of the total society" (GOODY, 1976: 9). This leads to considerations of the life cycle of domestic groups, which change every few years as the age of its members changes, and as economic circumstance demands. These are different determinants from the biological reproduction of members of the household, but clearly connected to them. Each phase of the domestic cycle is the outcome of a set of "pushes" and "pulls" and for this reason it is important that we not only take into account but that we seek to quantify the push and pull factors that result in particular behavioral outcomes, in this case particular human use of natural resources such as forested land.

A landscape is a mosaic made up of households at different stages in their developmental cycle and with different initial endowments. Figure 3 illustrates the conceptual framework that guided our research and that highlights the role of the developmental cycle over the life course as these relate to land use changes at the level of the individual property (see McCRACKEN et al. In press). The proposed stages are linked to different stages of the domestic cycle as young nuclear families migrate to the frontier, age over time, and then dissolve into multigenerational and second generation households as children reach adulthood. The diagonal from the upper left to the lower right corners represents our expectation of how these households will change their trajectories of land use. In stage I the young families will clear forest and plant annual crops at a relatively fast pace. In stage II they begin to shift their land use towards pasture and perennials made possible by some capital accumulation and increasing labor availability. In stages II and III the choice between cattle and perennials may be affected by a complex set of factors such as labor availability, credit, and the quality of soils. The households further shift in stage IV and V towards more labor saving activities as the head of household ages, but some households begin to experience some renewed forest clearing and annual crop production increases due to the change in generation from an older to a younger married son who takes over the property and starts the developmental cycle anew-albeit at more modest rates given the smaller proportions of forest available in the second generation.

Figure 3 Conceptual Framework of Household Transformations Land-Use and Environmental Change



The conceptual model proposed addresses issues of change over time. The issue of temporality is a complex one. The interaction of population with environment is not linear. Rather, it reflects the processes of systemic feedback experienced by both as interactions occur. These feedback processes are a product of the temporal changes marked by this interaction, and the system correction likely to occur over time as population learns from its mistakes and successes (MORAN, 1982), and as environment heals itself from the predatory actions of humans through its own restorative processes (MORAN et al. 1994b). Human action along a land use gradient will be episodic--at times moving towards degrading the environment, at others towards restoring it and sustaining it. As we will see in this paper, temporality explains a significant proportion of the deforestation outcome at a landscape level of analysis. Deforestation follows a predictable trajectory across migrant cohorts. This is a result of the loss of specificity in inter-household differences in demographic composition and capital when one aggregates differences between households at cohort scale. At household scale the explanations take a different turn. The transitions in land use and in rates of deforestation are hypothesized to be a product of household structure changing through time (Goody 1958, 1976).

IV. SAMPLING, PERIOD AND COHORT EFFECTS

One of the most serious challenges to social science research and environmental research has always been how to sample from the universe being studied. It is well-known that a population exists in space and time, but rarely have these considerations driven sampling approaches. Opportunistic, stratified and random sampling are all used, depending on the knowledge base present. Random samples are difficult to draw in much of the rural Third World because of the absence of any complete list of a population and its precise address. Stratification assumes a very extensive data on socio-economic status, demographic structure, and other criteria for stratifying a population that is rarely available, especially in tropical rain forest frontiers. Opportunistic sampling can be productive, particularly in exploratory research, but is likely to misrepresent the total population. What to do?

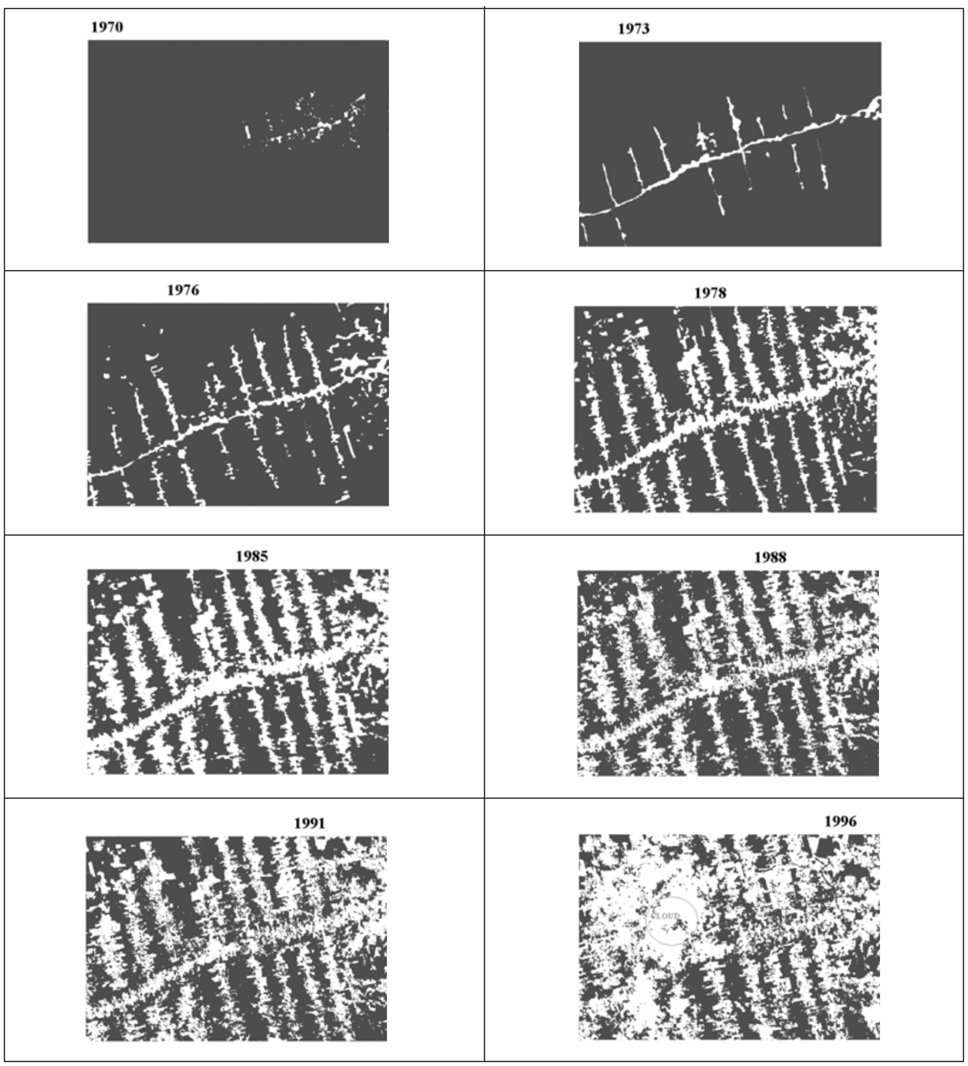
A useful conceptual tool that we turned to is the demographic perspective of cohort, age, and period effects. An age effect reflects similar patterns of change by length of time irrespective of when the households arrived at a place or what types of policies may have influenced them. A cohort effect is one in which some event or process common to a group of households results in a distinctive pattern of behavior. Timing of arrival on the frontier is a clear marker for defining a cohort and that allows for exploration of possible cohort effects. Individuals and households settling during the same period experience many similar opportunities and constraints which are markedly different from others arriving later (e.g. changes in off-farm employment opportunities, particular credit policies, road conditions, commodity prices). These shared experiences within a cohort vis-a-vis other cohorts may result in different patterns of deforestation and land use, than those explainable by either age or period effects. Period effects are felt by all cohorts equally. For example, any household in the landscape would experience inflation rate of 200 percent annually equally, without regard for how long they have been on the farm or what cohort they belonged to. Distinguishing between cohort and period effects will be particularly interesting and challenging in this paper. To do so we have to compare different cohorts at different points in time.

To accomplish this objective one must first ensure that each household in the study can be precisely located in space, i.e. spatially georeferenced, in terms of latitude/longitude to within 15 meter accuracy using Global Positioning System (GPS) devices. Since most households in this frontier live "on the land" rather than in town or in a nucleated settlement, location of the household in precise terms offers the advantage of return visits, as well as location of major features of their land use (major fields, pastures, plantations), that permit household-level information to be scaled upwards to a satellite image, Landsat Thematic Mapper digital data with 30 meter resolution. The advantage of this procedure is that the 402 households that were included in the household survey, and their landed property, are precisely known on a landscape of many thousands of square kilometers. In addition, the detailed examination of the 402 households will permit the extrapolation of these findings to the entire area of 3,800 square kilometers.

Implicit in this approach is a view that households change over time, and are affected by external forces. A landscape is a mosaic made up of households at different stages in their developmental cycle and with different initial endowments. In Figure 3 we presented the conceptual framework that guided our research and that highlights the role of the developmental cycle over the life course as these relate to land use changes at the level of the individual property.

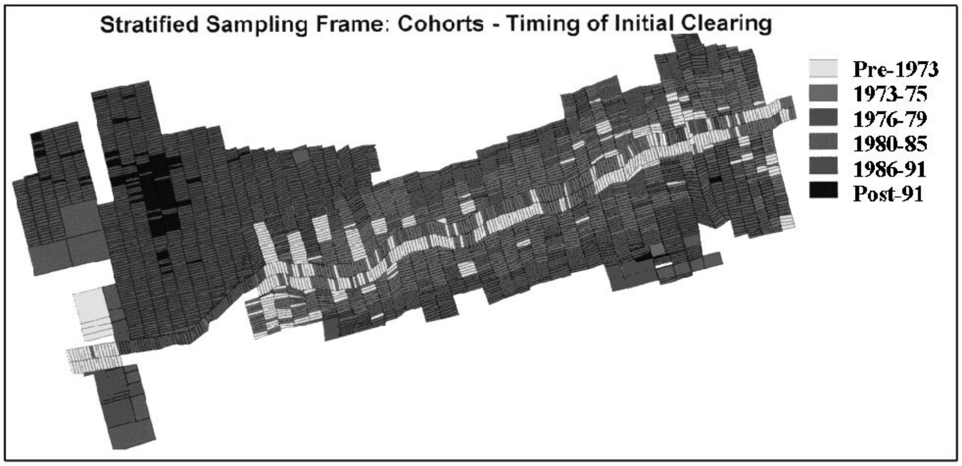
We began by acquiring a time-series of satellite digital data complemented with aerial photos to build up a GIS overlay at three year intervals for the study region (show the time series here, figure 4) that allows for examination of changing rates of deforestation. In order to address processes at the level of households, we overlayed a property grid with 3,800 properties on the remotely-sensed data, and added other layers as well such as the hydrography, roads, and topography. The grid allowed us to focus on the individual household and to use the criterion of when we first saw deforestation on a given property to assign each property to a cohort. The criterion we applied was evidence for 5 hectares cleared, since the average area cleared per year is 2 to 3 hectares, and our time-series satellite data was at three year intervals. Even if a household was below average at 2 ha per year, it would still be captured in our sampling scheme. A full description of the property grid development and its value for analysis can be found in McCracken et al. (1999).

Figure 4 "Time Series of Deforestation: 1970 - 1996".



We divided the population into 5 strata or cohorts and sampled disproportionately from each one so as to have relatively equal sized cohort groups of settlers. Figure 4 illustrates the distribution of the cohorts on the study area and Figure 5 illustrates the distribution of households over their time of arrival on the properties. We completed a sample of 402 household surveys that examined the demographic and socioeconomic history of families in the study area.

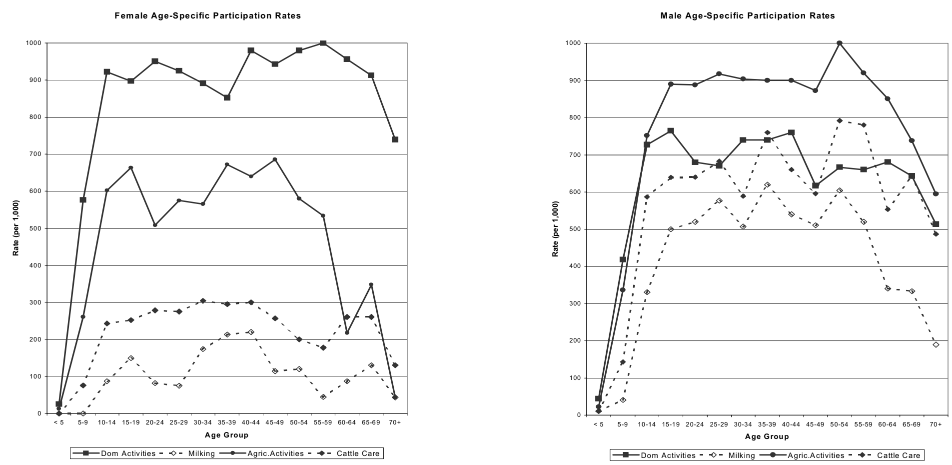
Figure 5



V. THE DIVISION OF LABOR

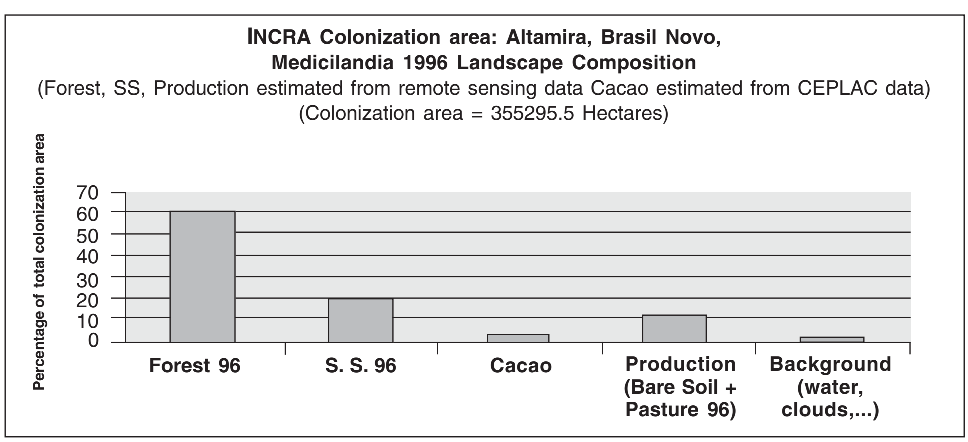
Our analysis found that family labor represented 84 percent of labor inputs for the oldest cohort of settlers, and over 93 percent for the most recent settlers. In no case does either sharecropping or hired labor represent more than 10 percent of labor inputs. This should result in a particularly important role for the size, age, and gender composition of households in the trajectories of land use found in the study area. In examining the age and gender participation of household members in different agricultural activities, we find a not overly segregated division of labor but a rather flexible allocation of household labor (see Figure 6, age-sex specific rates of participation). Either male or female-headed households (without a partner) are virtually unheard of in this region. Whenever a male or female head of household is widowed or divorced, they very quickly find a new partner on the grounds that it is not possible to sustain a farm without a partner.

Figure 6, "Age-Specific Participation Rates".



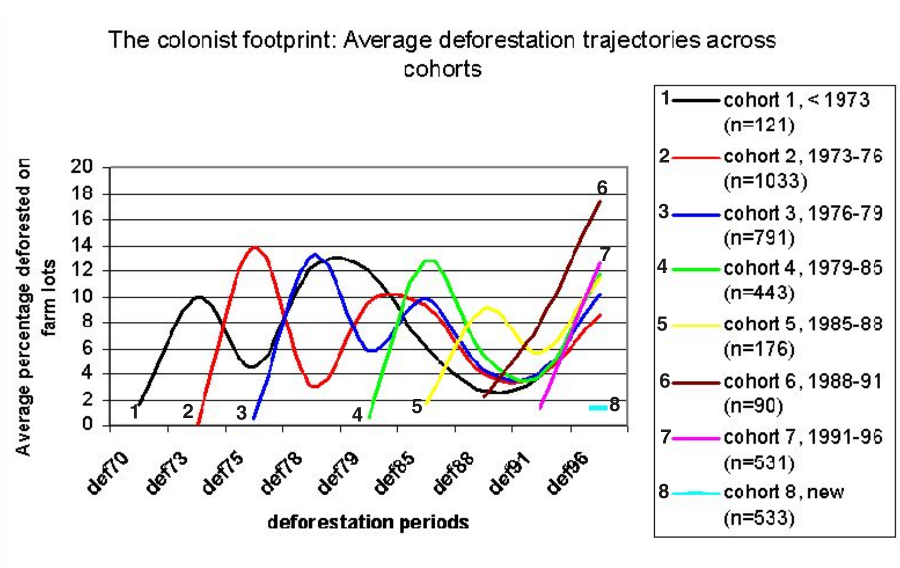
As families arrive in the frontier they are characteristically younger households, and there are slightly more males than females. Over time, the children leave the household. More females than males leave the household, and they leave it earlier, mostly through marriage to either create new farm households, or by moving to the city. Women tend to seek out an education disproportionally to males in the frontier. By age 20-24 there are nearly 3.5 times more sons remaining in households than daughters (McCRACKEN & SIQUEIRA, 2000). While farm households lose many females, they also gain them as daughters-in-law. The pattern in this frontier is surprisingly urban: most households are nuclear rather than extended families or multigenerational families. This is important, as we shall see, because the fertility of these women is remarkably urban.

Figure 7

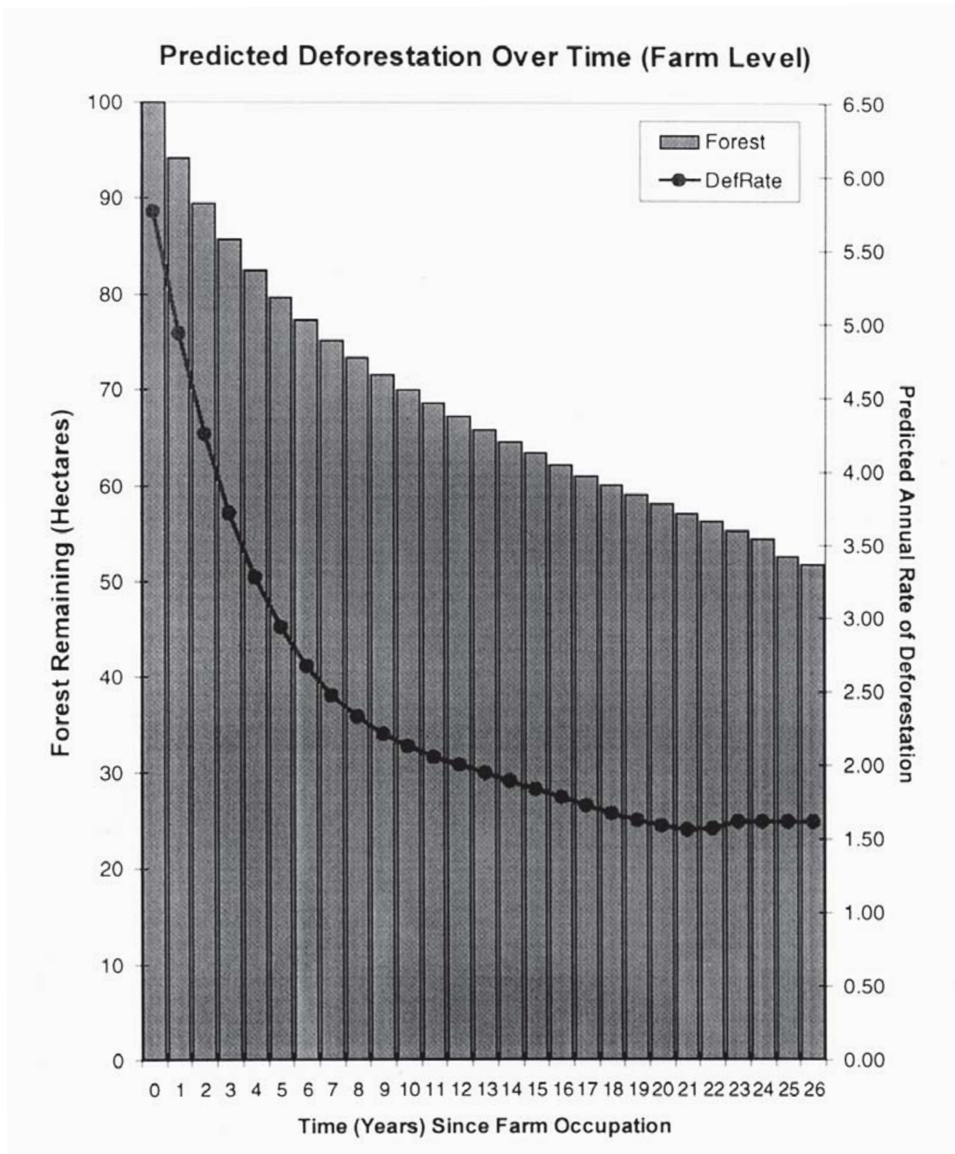


The analysis of the satellite time series shows that despite the visually dramatic rates of deforestation, 61 percent of the area remained in primary forest in 1996. Furthermore, only half of the area deforested was "in production" in 1996, with the other half at various stages of fallow or secondary growth (figure 7). As our conceptual model proposed, we find that each cohort engages in an accelerated period of deforestation of about 6% (in stage I) and focuses on annual cropping. This stage is followed by a slow down in the rate of deforestation in stages II and III where the rate of deforestation drops gradually to about 2-3%, and falling further in stages IV and V to about 1.6%. (see Figure 8, cohorts and deforestation and Figure 9, farm level predictions).

Figure 8

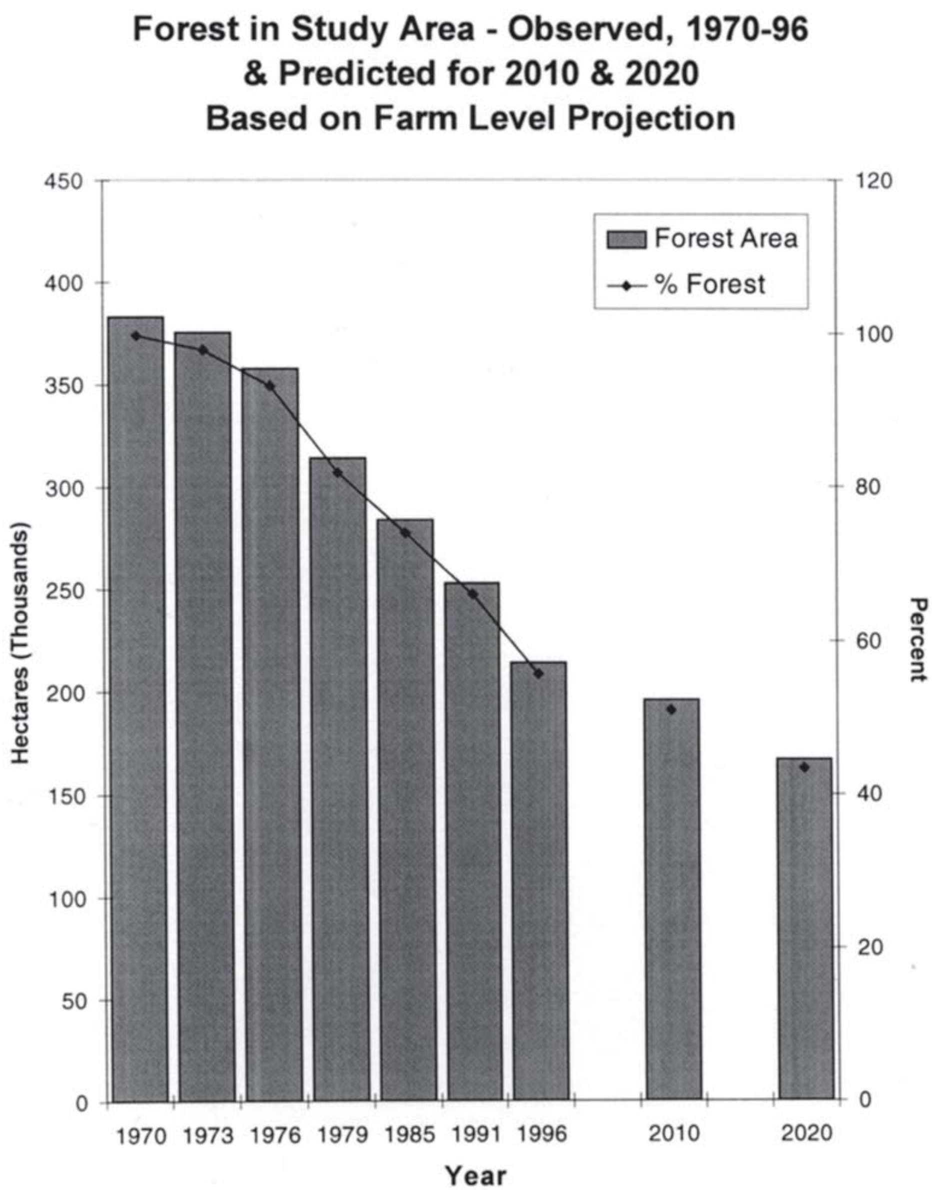


Figures 9a



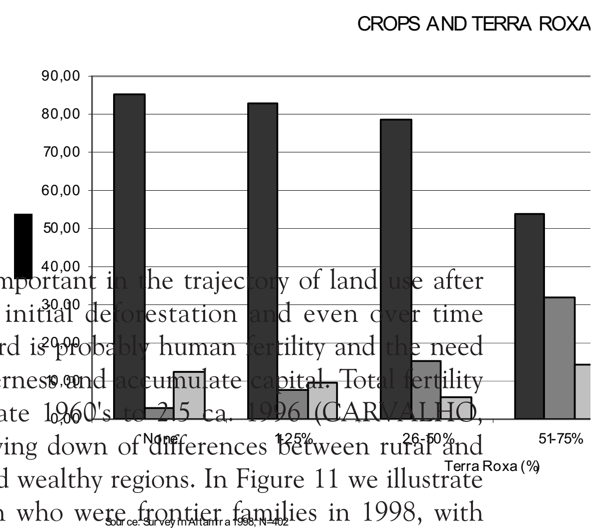
Predicted Deforestation Over Time (Farm Level)
Forest
DefRate
Forest Remaining (Hectares)
Predicted Annual Rate of Deforestation
Time (Years) Since Farm Occupation
100
90
80
70
60
50
40
30
20
10
0
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26

Figure 9b



Rates of deforestation and cropping pattern are affected not only by the demographic composition of households but by the initial biophysical endowments found on the property, particularly the fertility of the soils on the property (MORAN et al. 2000, in press). We found a linear relationship between the proportion of high quality soils on the property (terra roxa estruturada eutrofica or alfisols) and the proportion of the property in perennial cash crops. Whereas properties that are characterized by acid, low nutrient soils have over 80% of the cleared area in pasture, this proportion drops below 50% as the proportion of good soils increases, and in properties dominated by good soils there is a balance in land use between pasture and cropping (see figure 10).

Figure 10



While soil fertility is clearly important in the trajectory of land use after deforestation, it is less so in explaining initial deforestation and even over time deforestation. More important in this regard is probably human fertility and the need of households to create a farm in the wilderness and accumulate capital. Total fertility rates in Brazil dropped from 5.8 in the late 1960's to 2.5 ca. 1996 (CARVALHO, 1998). Moreover, there has been a narrowing down of differences between rural and urban patterns, and even between poor and wealthy regions. In Figure 11 we illustrate the total fertility of our sample of women who were frontier families in 1998, with estimates of regional rural and urban patterns from the Demographic and Health Surveys of 1986 and 1996. Fertility in our study area maintains rates of one child less than Northeast rural regions, and about 0.5 above the rates for Brazil as a whole. Women have dramatically altered their fertility behavior in less than a generation. Significant fertile decline for Brazilian women began with women born in the 1940's (Carvalho 1998). Women born in the early 1950's are the first cohorts to have reductions in age-specific fertility at both younger and older ages. Contributing to the maintenance of low fertility may have been the remarkably low infant mortality experienced in this frontier region. Whereas the rate of infant mortality experienced by women from the Northeast for children before migrating was 165, among families in the study area the rate was 40 deaths per thousand live births by the mid-1980's.

Figure 11a, "Trends in Total Fertility by Region & Rural-Urban Residence".

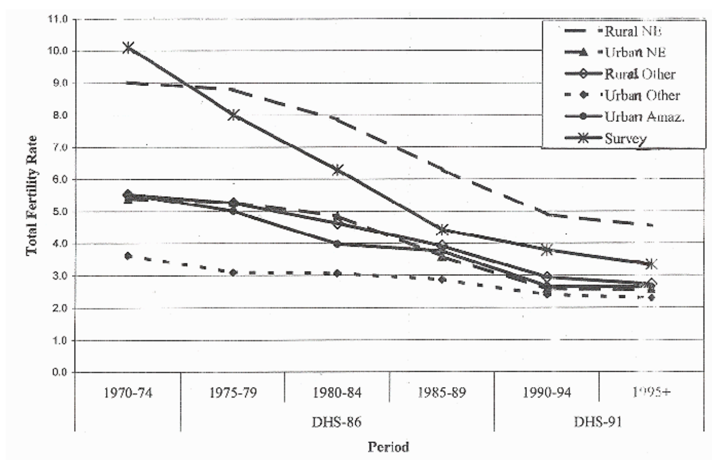
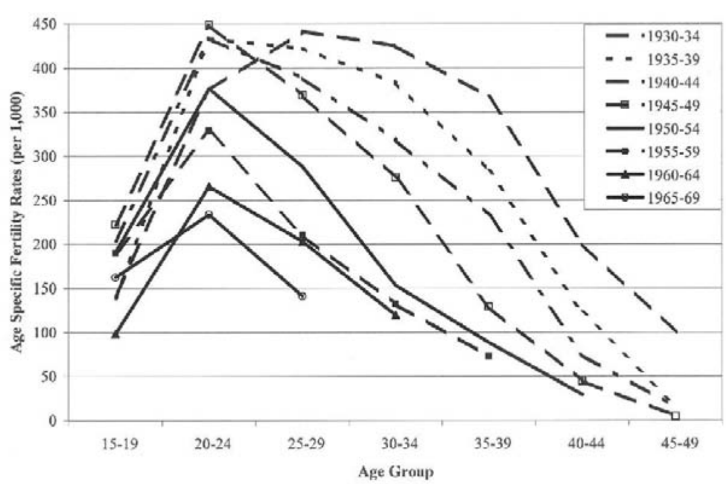


Figure 11b, "Age Specific Fertility Rates"



A surprising finding from our study is that fertility is in very rapid decline not only in Brazil as a whole but even in this relatively recent frontier region. Women use a variety of methods of fertility control and reduction. Most notable among these is the widespread use of sterilization, commonly after having two children. By age 25-29, we found that over 43% of women were sterilized (see Table 1) and that the proportion continues to increase with age. This finding has enormous implications for the future of this, and other, Amazonian regions. Since these families have relatively few children, they lack the labor to apply to the farm and are tied to a cycle of hiring labor during periods of peak labor demand. They are also reliant either on high profit margins that permit them to hire labor, or on favorable interest rates for loans which are routinely applied to hiring labor. When interest rates are high, or when commodity prices go down for a cycle, farmers may not be able to keep up their farms and will be pressured to sell, further exacerbating the rural to urban migration that we have seen taking place in Brazil, and the Amazon, for more than two decades. This process of urbanization of the rural population will reproduce the patterns of unequal land distribution and land concentration found in Northeast Brazil and Southern Brazil.

Table 1, "Contraceptive Use Among Married Women by Age-Group, Colonization Area, Altamira

Age Group	Method used Currently			Past Contraceptive Use		
No. (row %)	Pill	Other	Steriliz	Past-Use	Never	Total
15-19	15	1	3	18	3	40
	(37.50)	(2.50)	(7.50)	(45.00)	(7.50)	(100.00)
20-24	14	3	5	37	7	66
	(21.21)	(4.55)	(7.58)	(56.06)	(10.61)	(100.00)
25-29	6	0	27	28	1	62
	(9.68)	(0.00)	(43.55)	(45.16)	(1.61)	(100.00)
30-34	2	3	29	7	3	44
	(4.55)	(6.82)	(65.91)	(15.91)	(6.82)	(100.00)
35-39	0	1	43	10	3	57
	(0.00)	(1.75)	(75.44)	(17.54)	(5.26)	(100.00)
40-44	2	1	37	4	2	46
	(4.35)	(2.17)	(80.43)	(8.70)	(4.35)	(100.00)
45-49	0	0	30	6	5	41
	(0.00)	(0.00)	(73.17)	(14.63)	(12.20)	(100.00)
50-54	0	1	29	12	4	46
	(0.00)	(2.17)	(63.04)	(26.09)	(8.70)	(100.00)
55-59	0	0	20	11	13	44
	(0.00)	(0.00)	(45.45)	(25.00)	(29.55)	(100.00)
60-64	0	0	16	30	16	62
	(0.00)	(0.00)	(25.81)	(48.39)	(25.81)	(100.00)
Total	39	10	239	163	57	508
	(7.68)	(1.97)	(47.05)	(32.09)	(11.22)	(100.00)

CONCLUSIONS

In this paper we have presented a set of methods that allows examination of population and environment interactions in such a way that one can explicitly address the influence of environmental factors such as soil quality and geospatial location, the influence of cohort, period and age effects, and differences in household composition. Moreover, it allows examination of processes at both landscape and household levels of analysis. We have found that at the landscape level, cohort and age effects explain the trajectory of deforestation but that the magnitude of deforestation at the landscape level is best explained by period effects (such as the hyperinflation and tight credit experienced by the study families during the mid-1980's and early 1990's). However, at the household level, we find that deforestation follows the logic of the developmental cycle of domestic groups given their high dependence on family labor for almost 90% of labor used on the farm. Over time their strategies of land use are affected by their ability to hang on to members, rather than see them spin off to form new households, or to attract more daughters in law through marriage- and by the endowments that they gradually learn they have on the farm (e.g. soil quality, water sources, steep topography). The poorer the endowment the more likely the land is to move in the direction of pasture and cattle. Better lands will tend to have a more balanced land use allocation between pasture and perennials, with very small amounts of annual crops to meet family needs.

As a result of this analysis several research questions emerge. While households do follow the logic of the developmental cycle, there are clearly other factors at play as well. When they come into play varies according to a complex interaction between demographic, socioeconomic and environmental conditions. This interaction needs to be modeled with greater detail and sophistication. To do so will require study of other regions where the length of settlement has been longer than in this frontier, and with a larger sample of households to represent inter-generational processes. Documenting the response of households to credit incentives and fluctuations in commodity prices and the wildly fluctuating inflation rates in Brazil has proven to be challenging. Time-series of these factors are often incomplete or hard to interpret. In the frontier there are highly variable prices offered to farmers as a result of the ease or difficulty of reaching them to market their commodities. Sole reliance on average prices for a period may not reflect the farm gate prices of a portion of the population studied. The applicability of the methods we have developed is being implemented in two other areas of the Amazon where we have been able to obtain property grids. Nevertheless, we recognize that for many parts of the world where such property boundaries are not available, or where plots are very small and households live in villages rather than on their property, the linkage between household decisions and land use may be much more difficult to make without virtually complete demographic surveys, as has been done by the University of North Carolina population researchers working in Nang Rong district in Thailand.

The fertility decline found in this and other Amazonian frontiers, as in the rest of Brazil, speaks to the importance of macroeconomic and macropolitical forces in changing the demography of almost all regions of Brazil, regardless of context and even of the demand for labor inherent in a frontier. This results in a frontier over time that has less population pressure, that is more urban in character, and that may have a tendency towards labor saving forms of land use such as pasture and cattle ranches. Interestingly, these less intensive forms of land use commonly result in greater deforestation since the agents of deforestation shift from small farmers to larger urban-based entrepreneurs with enough capital to deforest large areas and to keep the forest from returning.

This study illustrates the importance of interdisciplinary, spatially-explicit analysis of the interaction between population and environment. We have found that explanations tend to be scale-specific, and the interdependencies among physical and social determinants result in surprising outcomes, such as the low fertility of frontier women, the ineluctable trajectory of land use over time, and the impact of the political economy on the magnitude of deforestation.

Acknowledgments

The authors wish to thank the Population and Social Sciences Study Group at the National Institute for Child and Human Development at NIH for the grant that made this study possible (9701386A). We also wish to thank the National Science Foundation which made possible the acquisition of the satellite data and earlier research in the study area on vegetation and secondary succession (9310049 and 9521918). We also wish to thank the many other members of our research group who have contributed to data collection and analysis over the past 4 years (Eduardo Brondizio, Andrea Siqueira, Stefano Fiorini, Lindan Hill, Bruce Boucek, Keshav Bhattarai, and Donald R. Nelson.). We also thank the many enumerators who assisted us in the data collection, and the 402 families for their great patience in answering our endless questions. They, nor any of the funding agencies and colleagues noted above, should be blamed for any of the views expressed in this paper. Responsibility for the views expressed remain the sole responsibility of the authors.

REFERENCES CITED

ABER, J.D. & MELILLO, JM.. **Terrestrial Ecosystems**. Philadelphia: Saunders Publishing, 1991.

ALMEIDA, A.O. de "Parceria e Tamanho da familia no nordeste brasileiro" *Pesquisa e Planejamento Economico* 7 (2): 291-331, 1977.

________ . **Colonizacao na Amazonia**. Rio de Janeiro: IPEA, 1992.

ALTER, G. & RILEY, J. Frailty, Sickness, and Death: Models of Morbidity and Mortality in Historical Populations. Population Studies 43: 25-45, 1989.

ANDERTON, D.L.; ANDERSON, A.B.; OAKES, J. & FRASIER, M. Environmental Equity: the demographics of dumping. *Demography* 31: 221-240, 1994.

ANDREAE, M.O. & SCHIMEL, D.S. (eds.)**Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere**. Wiley-Interscience: New York, 1989.

BALTAXE, R. **The Application of Landsat Data to Tropical Forest Surveys**. Rome: FAO, 1980.

BILSBORROW, R. Population pressure and agricultural development in developing countries:a conceptual framework and recent evidence. *World Development* 15(2):183-203, 1987.

BILSBORROW, R. & OGENDO, H. Population driven changes in land use indeveloping countries. *Ambio* 21(1): 37-45, 1992.

BILSBORROW, R. & DELARGY, P. Land Use, Migration, and Natural Resource Deterioration: The Experience of Guatemala and the Sudan. In: DAVIS, K. & BERNSTAM, M. (eds.) **Resources, Environment and Population**, New York: Oxford University Press, 1991.

BIRDSALL, N. **Another Look at Population and Global Warming**. World Bank Policy Research Working Papers, WPS 1020, 1992.

BONGAARTS, J. Population Growth and Global Warming. *Population and Development Review* 18: 299-319, 1992.

BONGAARTS, J. Demographic Consequences of Declining Fertility. *Science* 282:419-420, 1998.

BONHAM, C.D. **Measurements for Terrestrial Vegetation**. New York: Wiley, 1989.

BOOTH, W. Monitoring the fate of forests from space. *Science* 243: 1428-1429, 1989.

BOSERUP, E. **The Conditions of Agricultural Growth**. London: Methuen, 1965.

BRONDIZIO, E.S.; MORAN, E.F.; MAUSEL, P. & WU, Y. Land use change in the Amazon estuary: Linking of the thematic mapper with botanical and historical data. *Photogrammetric Engineering and Remote Sensing*. 62(8):921-929, 1996.

BROWDER, J. Public policy and deforestation in the Brazilian Amazon. In: REPETTO, R. & GILLIS, M.(ed.)**Public Policies and the Misuse of Forest Resources**. Washington DC: World Resources Institute, 1988.

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

BROWN, S. & LUGO, A.E. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica* 14:161-187, 1982.

________ . Biomass of tropical forests: a new estimate based on forest volumes. *Science* 223:1290-1293, 1984.

________ . Above-ground Biomass estimates for Tropical Moist Forests of the Brazilian Amazon. *Interciencia* 17(1): 1-14, 1992.

CARVALHO, J. Demographic Dynamics in Brazil; Recent Trends and Perspectives. *Brazilian Journal of Population Studies.* 1(1997/98):5-23, 1998.

COMMITTEE ON EARTH AND ENVIRONMENTAL SCIENCES. **Our Changing Planet: The FY 1991 Research Plan for U.S. Global Change Research Programs**. Office of Science and Technology Policy. Office of the President. Washington, D.C., 1990

CRAMEER, J.C. Population Growth and Air Quality in California. *Demography* 35: 45-56, 1998.

CRUMLEY, C. (ed.) **Historical Ecology**. Santa Fe, NM: School of American Research Press, 1994.

CRUTZEN, P.J. & ANDRAE, M.O. Biomass burning in the tropics: impacts on atmospheric chemistry and biogeochemical cycles. *Science* 250:1669-1678, 1990.

DALE, V.H.; HOUGHTON, R.A. & HALL, C.A.S. Estimating the effects of land-use change on global atmospheric CO2 concentrations. *Canadian Journal of Forestry Research* 21:87-90, 1991.

DANJOY, W.A. Use of remote sensing for monitoring and control of deforestation in the high jungle of Peru. **Proceedings of the 18th International Symposium on Remote Sensing of the Environment**. Ann Arbor, MI: Environmental Research Institute of Michigan, 1984.

DANTAS, M. **Studies on Succession in Cleared Areas of Amazonian Rain Forest**. Ph.D. thesis, Oxford University, 1988.

DENEVAN, W. & PADOCH, C. (eds.) **Swidden Fallow Agroforestry in Amazonia**. Monographs in Economic Botany. New York Botanical Garden. New York, 1988.

DETWILER, R.P. & HALL, C.A.S. Tropical forests and the global carbon cycle. *Science* 239:42-47, 1988.

DICKINSON, R.E. & KENNEDY, P. Impact on Regional Climate of Amazon Deforestation. *Geophysical Research Letter* 19:1947-1950, 1992.

DICKINSON, R.E. Predicting Climate Effects. *Nature*. 342:343-344, 1989.

DICKINSON, R.E. (ed.) **The Geophysiology of Amazonia: Vegetation and Climate Interactions**. Wiley: New York, 1987.

EASTERLIN, R.; CONDRAN, G. & ALTER, G. Farms and Farm Families: the North in 1860. In: HAREVEN, T. & VINOVSKIS, M. (eds.) **Demographic Processes and Family Organization.** Princeton: Princeton University Press, 1978.

EDEN, M.J. & PARRY, J.T. (eds.) **Remote Sensing and Tropical Land Management.** Wiley. New York, 1986.

ENTWISLE, B.; RINDFUSS, R.R.; GUILKEY, D.K. et al. ACommunity and Contraceptive Choice in Rural Thailand: Case Study of Nang Rong. *Demography*. 33:1-11, 1996.

ENTWISTLE, B.; WALSH, S.; RINDFUSS, R. & CHAMRATHITHIRONG, A. Land Use/Land Cover and Population Dynamics, Nang Rong, Thailand. Pp.121-144, In: LIVERMAN, D.; MORAN, E.; RINDFUSS, R. & STERN, P. (eds.) **People and Pixels: Linking Remote Sensing and Social Science.** Washington DC: National Academy Press, 1998.

ESTES, J. & Cosention, M.J. Remote sensing of vegetation. Pp.75-111 In: RAMBLE, M.B.; MARGULIS, L. & FESTER, R. (eds.) **Global Ecology: Towards a Science of the Biosphere**. New York: Academic Press, 1988.

FEARNSIDE, P.M. 1983. Land-use trends in the Brazilian Amazon region as factors in accelerating deforestation. *Environmental Conservation* 19:141-148, 1983.

________ . Brazil's Amazon forest and the global carbon problem. *Interciencia* 10: 179-186, 1985.

________ . Causes of deforestation in the Brazilian Amazon. Pp. 37-57 In: DICKINSON, R.E.(ed.) **The Geophysiology of Amazonia**. Wiley: New York, 1987.

FEARNSIDE, P.M. A prescription for slowing deforestation in Amazonia. *Environment* 31: 17-20, 39-40, 1989.

FLEMING-MORAN, M. **The Folk View of Natural Causation and disease in Brazil and its relation to traditional curing practices**. M.A. thesis, University of Florida, Deptartment of Anthropology, 1975.

FLEMING-MORAN, M. The Folk View of natural causation and disease in Brasil and its relation to traditional curing practices. *Boletim do Museu Paraense Emilio Goeldi Antropologia*. 8(1):65-156, 1992.

GEIST, H.J. & LAMBIN, E.F. What Drives Tropical Deforestation: A meta-analysis of proximate and underlying causes of deforestation based on subnational case study evidence. *LUCC Report Series No. 4* LUCC International Project Office. Louvain, Belgium, 2001.

GILLIS, M. & REPETTO, R. eds. **Public Policies and the Misuse of Forest Resources**. New York: Cambridge Univ.Press/World Resources Inst, 1988.

GOODY, J. **The Develpoment Cycle of Domestic Groups.** New York: Cambridge University Press, 1958.

GOODY, J. **Production and Reproduction: A Comparative Study of the Domestic Domain.** New York: Cambridge University Press, 1976.

GRAINGER, A. Improving the monitoring of deforestation in the humid tropics. Pp. 387-395 In: SUTTON, S.; WHITMORE, T.C. & CHADWICK, A. (eds.) **Tropical Rain Forests: Ecology and Management.** Oxford: Blackwell, 1983.

GREEN, K.M. Using Landsat to monitor tropical forest ecosystems: realistic expectations of digital processing technology. Pp. 397-409 In: SUTTON, S.; WHITMORE, T.C. & CHADWICK, A. (eds.) **Tropical Rain Forests: Ecology and Management**. Oxford: Blackwell, 1983.

GREEN, S.M. & SUSSMAN, R. Deforestation history of the eastern rain forests of Madagascar from satellite images. *Science* 248: 212-215, 1990.

GUTMANN, M. & ALTER, G. Family Reconstitution as Event History Analysis. In: REHER, D. & SCHOFIELD, R. (eds.)**Old and New Methods in Historical Demography.** Oxford: Oxford University Press. In press.

GUYER, J. & LAMBIN, E. Land Use in an Urban Hinterland: Ethnography and Remote Sensing in the Study of African Intensification. *American Anthropologist* 95(3): 17-37, 1993.

HELFERT, M.R. & LULLA, K.P. Mapping continental-scale biomass burning and smoke palls over the Amazon Basin as observed from the space shuttle. *Photogrammetric Engineering and Remote Sensing* 56:1367-1373, 1990.

HENDERSON-SELLERS, A. **Effect of Change in Land Use on Climate in the Humid Tropics. The Geophysiology of Amazonia.** Edited by R. Dickinson. New York: Wiley, 1987.

HOFFER, R.; LOZANO-GARCIA, M.; GILLESPIE, D.F.; MUELLER, P.W.& RUZEK, M. Analysis of multiple incidence Angle SIR-B data for determining forest stand characteristics. Pp. 159-164 In: **Second Spaceborne Imaging Radar Symposium.** Jet Propulsion Laboratory. Pasadena, CA, 1986.

HOGAN, D.J. The impact of population growth on the physical environment. *European Journal of Population.* 9: 109-123, 1992.

HUNTER, L.M. The association between environmental risk and internal migration flows. *Population and Environment*. 19 (3): 247-277, 1998.

IBGE. Instituto Brasileiro de Geografia e Estatística. Census numbers consulted in 1991. <http://www.ibge.gov.br/>

JORDAN, C.F. &. UHL, C. Biomass of a "terra firme" forest of the Amazon Basin. Oecologia Plantarum 13:387-400, 1978.

JORDAN, C.F. (ed.). **An Amazonian Rain Forest**. UNESCO Man and the Biosphere Series Vol. 2. Casterton Hall, England: Parthenon Publishing, 1989.

LEAN, J. & WARRILOW, D. Simulation of the Regional Climate Impact of Amazon Deforestation. Nature 342:411-412, 1989.

LI, Y; MORAN, E.F.; BRONDIZIO, E.S.; MAUSEL, P. & WU, Y. Discriminating between Advanced Secondary Succession and Mature Moist Forest in Altamira, Para, Brazil. **Proceedings of the Society for Photogrammetric Engineering and Remote Sensing.** Reno Nevada, 1994.

LIBECAP, G. & ALTER, G. Agricultural Productivity, Partible Inheritance, and the Demographic Response to Rural Poverty: An Examination of the Spanish Southwest. *Explorations in Economic History* 19: 184-200, 1982.

LILLESAND, T.M. & KIEFER, R.W. **Remote Sensing and Image Interpretation.** New York: Wiley, 1979.

LINDGREN, D.T. **Land Use Planning and Remote Sensing.** Nijhoff. Dordrecht, 1985.

LOVELL, P. **Child Survival in the Brazilian Amazon**, 1960-1980. Unpubl. Ms, 1994.

LUCAS, R. & STARK, O. Motivations to Remit: Evidence from Botswana. *Journal of Political Economy* 47:8-27, 1985.

LUTZ, W. Introduction. In: LUTZ, W. (ed) **Population-Development-Environment: Understanding their Interactions in Mauritius**, pp 1-8. New York: Springer-Verlag, 1994b.

MAHAR, D. **Government Policies and Deforestation in Brazil's Amazon Region.** Washington, D.C.: World Bank, 1988.

MALINGREAU, J. & TUCKER, C.J. Large scale deforestation in the southeastern Amazon basin of Brazil. *Ambio* 17:49-55, 1988.

MAUSEL, P.; WU, Y. et al Spectral Identification of Successional Stages following Deforestation in the Amazon. *Geocarto International* 8(4):61-71, 1993.

MAUSEL, P. & MORAN, E. Discriminating between oxisols and alfisols in Altamira, Para, Brazil. **Proceedings of the International Society for Photogrammetric Engineering and Remote Sensing**. Rio de Janeiro, Brazil, 1994.

MCCRACKEN, S.D.; BRONDIZIO, E.S. et al.Remote Sensing and GIS at Farm Property Level: Demography and Deforestation in the Brazilian Amazon. *Photogrammetric Engineering and Remote Sensing.* 65(11)1311-1320, 1999.

McCRACKEN, S.D.; SIQUEIRA, A.D. et al. Land Use Patterns on an Agricultural Frontier in Brazil; Insights and examples from a demographic perspective. In: *Land Use and Deforestation in the Amazon*. Edited by C.H. Wood and R. Porro. Gainesville: University Press of Florida. In press.

MCCRACKEN, S.D. AND A.D. SIQUEIRA. **Fertility Decline on an Amazonian Agricultural Frontier of Brazil: New Evidence for Old Debates.** Unpublished manuscript.

MERRICK, T. Fertility and Land Availability in rural Brazil. *Demography* 15 (3): 321-336, 1978.

MOLION, L. Micrometeriology of an Amazonian Rain Forest. In: DICKINSON, R. (ed.) *The Geophysiology of Amazonia*. New York: Wiley, 1987.

MOURA, R. & ROSA, J. **A questao da saude na Amazonia**. Rio de Janeiro: CNPq, 1989.

MORAN, E.F **Agricultural Development Along the Transamazon Highway**. Center for Latin American Studies Monograph Series. Bloomington: Indiana University, 1976.

________ . **Human Adaptability: An Introduction to Ecological Anthropology.** Boulder, CO: Westview Press, 1979.

________ . **Developing the Amazon.** Bloomington, IN: Indiana University Press, 1981.

________ . Ecological, anthropological and agronomic research in the Amazon basin. *Latin American Research Review* 17:3-40, 1982.

________ . Socio-economic considerations in acid tropical soils research. In: SANCHEZ, P.; PUSHPARAJAH, E. & STONER, E. (eds.) **Management of Acid Tropical Soils for Sustainable Agriculture.** Bangkok: International Board for Soil Research and Management, 1987.

________ . A Producao Agricola em um Projeto de Colonizacao em Carajas. In: KHOLHEPP, G. (org.) **Homem e Natureza na Amazonia.** Tubingen, Germany: Tubinger Geographische Studien No. 95: 353-366, 1988.

________ . Models of native and folk adaptation in the Amazon. *Advances in Economic Botany* 7:22-29, 1989.

________ . **A Ecologia Humana das Populacoes da Amazonia.** Editora Vozes. Petropolis, Brazil, 1990a.

________ . **The Ecosystem Approach in Anthropology: From Concept to Practice.** Ann Arbor: University of Michigan Press, 1990b.

________ . Human adaptive strategies in Amazonian blackwater ecosystems. *American Anthropologist* 93:361-382, 1991.

MORAN, E.F.; BRONDIZIO, E.S.; MAUSEL, P. & WU, Y. Integrating Amazonian Vegetation, Land use and Satellite Data. *BioScience* 44 (5): 329-338, 1994a.

MORAN, E.F.; BRONDIZIO, E.S. & MAUSEL, P. Secondary Succession. *Research & Exploration* 10(4): 458-476, 1994b.

MORAN, E.F.; BRONDIZIO, E.S.; TUCKER, J.M. et al. Effects of soil fertility and land-use on forest succession in Amazonia. *Forest Ecology and Management* 139:93-108, 2000.

MORAN, E.F. & McCRACKEN, S.D. The Development Cycle of Domestic Groups and Amazonian Deforestation. Paper presented at the Annual Meeting of the Population Association of America, March 29, 2001. Washington, D.C, 2001.

MORAN, E.F.; BRONDIZIO, E.S.; McCRACKEN, S. Trajectories of land use: Soils, succession, and crop choice. In: WOOD, C. & PORRO, R. **Land Use and Deforestation in the Amazon.** Gainesville: University of Florida Press In press.

MYERS **The Primary Source**. New York: Scribners, 1984.

NELSON, R. & HOLBEN, B. Identifying deforestation in Brazil using multi-resolution satellite data. *International Journal of Remote Sensing* 7:429-448, 1986.

NETO, J.M.S. Contraception in Frontier Regions. Paper presented at IUSSP, Campinas, Sao Paulo. Nov. 30-Dec. 3, 1992.

NETTING, R.; WILK, R. & ARNOULD, E. (eds.) **Households: Comparative and Historical Studies of the Domestic Group.** Berkeley: University of California Press, 1984.

NOBRE, C. & SELLERS, P. & SHUKLA, J. Amazonian Deforestation and Regional Climate Change. *Journal of Climate* 4:957-987, 1991.

PALLONI, A. The relation between population and deforestation: methods for drawing causal inferences from macro and micro studies. In: ARIZPE, L.; STONE, M.& MAJOR, D.C. (eds.) **Population and Environment: Rethinking the Debate.** pp. 125-165. Boulder: Westview Press, 1994.

PEBLEY, A.R. Demography and the Environment. *Demography* 35 (4):377-389, 1998.

PEBLEY, A.R.; GOLDMAN, N. & RODRIGUEZ, G. Prenatal and delivery care and childhood immunization in Guatemala: do family and community matter? *Demography*. 33(2):231-247, 1996.

PERZ, S.G. The rural exodus in the context of economic crisis, globalization and reform in Brazil. *International Migration Review.* 34(3):842-881, 2000a.

________ . The quality of urban environments in the Brazilian Amazon. *Social Indicators Research.* 49(2):181-212, 2000b.

PICHON, F. **Suggested Themes.** Paper for Workshop on Population, Environment and Development in Lowland Tropical South America. University of Pittsburgh. October 28-30, 1994.

________ . Settler agriculture and the dynamics of resource allocation in frontier environments. *Human Ecology.* 24(3):341-371, 1996a.

________ . Land-use strategies in the Amazon frontier: farm-level evidence frm Ecuador. *Human Organization.* 55(4):416-424, 1996b.

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

PICHON, F. & BILSBORROW, R. **Land Use Systems, Deforestation and Associated Demographic Factors in the Humid Tropics.** Paper prepared for the IUSSP Seminar on Population and Deforestation in the Humid Tropics.Campinas, SP, Brazil, 1992.

PICHON, F.& UQUILLAS, J.E. Agricultural intensification and poverty reduction in Latin America's risk-prone areas: opportunities and challenges. *Journal of Developing Areas.* 31(4):479-514, 1997.

PRANCE, G.T. & LOVEJOY, T.E. (eds.) **Key Environments: Amazonia**. Oxford: Pergamon Press, 1985.

PRESTON, S.H. The Effects of Population Growth on Environmental Quality. *Population Research and Policy Review* 15:95-108, 1996.

RINDFUSS, R.; WALSH, S. & ENTWISTLE, B. **Land Use, Competition and Migration.** Presented at the annual meeting of the Population Association of America, New Orleans, 1996.

ROTELLA, E. & ALTER, G. Working Class Debt in the late 19th Century. *Journal of Family History* 18 (2): 111-134, 1993.

SADER, S.A.; STONE, T. & JOYCE, A. Remote sensing of tropical forests: an overview of research and applications using non-photographic sensors. *Photogrammetric Engineering and Remote Sensing* 56:1343-1351, 1990.

SADER, S.A.; WAIDE, R.B.; LAWRENCE, W.T. & JOYCE. A. Tropical Forest biomass and Successional Age Class relationships to a vegetation index derived from Landsat TM data. *Remote Sensing of Environment* 28:143-156, 1989.

SALATI, E. The climatology and hydrology of Amazonia. In: PRANCE, G.T. & LOVEJOY, T.E. (eds.) **Key Environments: Amazonia.** Oxford: Pergamon Press, 1985.

SALATI, E. & VOSE, P.B. Amazon basin: a system in equilibrium. *Science* 225:129-138, 1984.

SAWYER, D. **Interdisciplinarity and Action in the Amazon.** Paper presented at workshop on "Population, environment and development in lowland tropical South America". University of Pittsburgh, Center for Latin American Studies, 1994.

SEILER, W. & CRUTZEN, P.J. Estimates of the gross and net flux of carbon between the biosphere and atmosphere from biomass burning. *Climatic Change* 2:207-274, 1980.

SETZER, A.W. & PEREIRA, M.C. Amazonia biomass burnings in 1987 and an estimate of their tropospheric emissions. *Ambio* 20:19-22, 1991.

SCHMINK, M. & WOOD, C. **Contested Frontiers of Amazonia.** New York: Columbia University Press, 1992.

_________ . **Frontier Expansion in Amazonia.** Gainesville: University Presses of Florida, 1982.

SHUKLA, J.; NOBRE, C. & SELLERS, P. Amazon deforestation and climate change. *Science* 247:1322-1325, 1990.

SILVER, C.S. **One Earth, One Future: Our Changing Global Environment.** National Academy of Sciences. Washington, D.C.: National Academy Press, 1990.

SKOLE, D. & TUCKER, C.J. Tropical Deforestation and Habitat Fragmentation in the Amazon: Satellite Data from 1978 to 1988. *Science* 260:1905-1910, 1993.

SMITH, N. *Rainforest Corridors.* Berkeley: University of California Press, 1982.

STERN, P.C.; YOUNG, O.R. & DRUCKMAN, D. **Global Environmental Change: The Human Dimensions.** Washington DC: National Academy Press, 1992.

STEWARD, D. **After the Trees.** Austin: University of Texas Press, 1994.

STONICH, S. The dynamics of Social Processes and Environmental Destruction: A Central American Case Study. *Population and Development Review* 15(2):269-296, 1989.

TURNER, B.L.; MEYER, W. & SKOLE, W.D. Global Land-Use/Land-Cover Change: Towards an Integrated Study. *Ambio* 23(1):91-95, 1994.

UHL, C. & VIEIRA, I.C.G. Ecological impacts of selective logging in the Brazilian Amazon: a case study from the Paragominas region in the state of Para. *Biotropica* 21:98-106, 1989.

VOSTI, S.A. **Malaria among Goldminers in Southern Para.** Washington DC: International Food Policy Research Institute paper, 1985.

WALSH, S.J.; EVANS, T.P.; WELSH, W.F.; ENTWISTLE, B. & RINDFUSS, R. Scale-Dependent Relationships between Population and Environment in Northeastern Thailand. *Photogrammetric Engineering and Remote Sensing.* 65(1):97-105, 1999.

WHITTAKER, R.H. & LIKENS, G.E. The biosphere and man. In: LEITH, H. & WHITTAKER, R.H. (eds.) **Primary Productivity of the Biosphere.** pp. 305-328. Berlin: Springer-Verlag, 1975.

WHITTAKER, R.H. & MARKS, P.L. Methods of assessing terrestrial productivity. In: LEITH, H. & WHITTAKER, R.H. (eds.) **Primary Productivity of the Biosphere.** pp. 55-118. Berlin: Springer-Verlag, 1975.

WOOD, C. & CARVALHO, J. **The Demography of Inequality in Brazil.** Cambridge: Cambridge University Press, 1988.

WOOD, C. & LOVELL, P. Indirect measures of child mortality: overview and applications to Brazil. *Social Indicators Research* 23: 247-267, 1990.

WOOD, C.H. & SKOLE, D. Linking Satellite, Census, and Survey Data to Study Deforestation in the Brazilian Amazon. In: LIVERMAN, D.; MORAN, E.F.; RINDFUSS, R. & STERN, P.C. **People and Pixels: Linking Remote Sensing and Social Science.** Edited by. Washington, D.C.: National Academy Press, 1998.

WOODWELL, G.M.; HOUGHTON, R.A.; STONE, T.A. & PARK, A.B. Changes in the areas of forests in Rondonia, Amazon Basin, measured by satellite imagery. In: TRABALKA, J.R. & REICHLE, D.E. **The Changing Carbon Cycle: A Global Analysis.** pp. 242-257. New York: Springer-Verlag, 1986.

WOODWELL, G.M.; HOUGHTON, R.A.; STONE, T.A.; NELSON, R.F. & KOVALICK, W. Deforestation in the tropics: new measurements in the Amazon basin using Landsat and NOAA advanced very high resolution radiometer imagery. **Journal of Geophysical Research** 92:2157-2163, 1987.

NOTE

1. Progress in the study of population and environment has been due in no small part to the support from NICHD's Social Science and Population Study Group, the National Science Foundation, and the National Aeronautics and Space Administration that have funded work linking demography to studies of land use and land cover change.