Population, agricultural land use and the environment in Latin America at the dawn of the 20th century: Evidence of change at the regional, national, and local scales

Carr, D.L., R.E. Bilborrow, and A. Barbieri (2003).

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Abstract: This paper considers the relationships between population, land use, and the environment in Latin America during the latter decades of the 20th century. Specifically, the possible implications of changes in population size, distribution, and density on changes in forest cover, agricultural land area, and agricultural technology are examined for the major Latin American nations. Differences in trends and patterns are identified both among countries and over time, with significant differences observed between Central and South America. Some case studies are examined in more detail to shed further light on factors that may be responsible for the regional and country differences observed, and which may bear upon patterns to be expected in the new millennium.

ABSTRACT

This is a review paper pursuant to the theme of population and environment, focusing on Latin America. The paper will briefly present theoretical approaches, critically review a number of empirical studies, identify gaps in knowledge, and suggest needed new directions for research. The focus will be on land resources, that is, the linkages between demographic processes and land, soils and forests. It will begin with a review of theoretical aspects of the relationships between trends in population, land use, and agriculture in Latin America from the 1960s to the turn of the millennium. Rapid population growth and redistribution through migration, agricultural expansion, and forest clearing occurred in the developing world during the second

half of the twentieth century, especially in Latin America. The population of the region tripled to 519 million by 2000 (UN, 2001), and became 75 percent urban, while the region experienced the fastest increase in agricultural land area and concomitantly the greatest percentage loss of forest cover of any world region: For example, during the first half of the 1990s twice as much forest was converted to agriculture as in any other world region: 57,800 km^2 per annum (World Bank, 1998). Thus even though fertility and population growth rates in most of the region moderated significantly in the latter quarter of the 20^{th} century, rural-rural migration movements and the expansion of the agricultural frontier at the expense of forests in the Amazon and elsewhere continue apace.

INTRODUCTION

This is a review paper pursuant to the theme of population and environment, focusing on Latin America. The paper will briefly present theoretical approaches, critically review a number of empirical studies, identify gaps in knowledge, and suggest needed new directions for research. The focus will be on land resources, that is, the linkages between demographic processes and land, soils and forests. We have now completed a century of population growth and landscape change unprecedented in the history of Latin America. Latin America's population (519 million by 2000) has approximately doubled in the past thirty years (UN, 2001). The region's population is expected to double again—to almost 1 billion—well before the end of next century, with almost all of the growth occurring in cities (UNFPA, 2000). The primary reason for the rapid population growth during the past half century was a dramatic decline in mortality due to improved health conditions and economic development while at the same time, until the last quarter century, fertility remained high. With the exception of "pioneers," such as Costa Rica and Cuba, where earnest fertility decline began in the 1960s, it was not until the 1970s that fertility began to generally fall in Latin America. Nonetheless, fertility decline has been delayed in certain Central American countries, namely Guatemala, Honduras, Nicaragua, and Haiti.

Most recently, the region has been characterized by moderately high, but falling, fertility and high rates of rural to urban migration. South America already have slightly more than three-quarters of their population living in urban areas while Central America is rapidly closing in at almost 70% urban (UNFPA, 2000). Even the largest frontier area in Latin America, the Brazilian Amazon, has faced a growing process of urbanization: of the 12 million inhabitants in the Brazilian Amazon in 2000 (7% of the total Brazilian population), 69.4% were living in urban areas (IBGE, 2000).

Urbanization and rural fertility decline occurred earlier in South America than in Central America. In fact, during the last three decades South America lost three million rural residents while Central America gained approximately eight million (Appendix). Most urban growth is expected to come from migration from rural areas. Rural out-migration proceeded at just under 1% per annum in Africa and Asia, and over 2% in Latin America from the 1960s to through the 1990s (Chen, et al., 1997). Most of this population movement has been to cities or to other countries (i.e., external migration).

As international debt repayment plans in the 1980s restructured rural economies towards cash crop exports, particularly cattle, coffee, cotton, and bananas, large export-oriented farms expanded, displacing smaller farmers from their land. Consequently, rural families were pushed from worsening conditions on the farm and pulled by the possibility of wage labor employment and improved education and health access in major cities. The benefits of globalization and international trade have not been equal, with farming subside or market protection in developed countries threatening the agricultural sustainability and living conditions of small farmers in developing countries. For example, depressed coffee prices in international markets dramatically decreased farm income in Ecuador in the 1990s (Bilsborrow et al, 2003). Improvement of communication and transportation systems has also diminished the financial and emotional costs of population mobility, thus facilitating rural-urban migration. International migration has also been a frequent individual and household strategy, which includes traditional migration areas to the United States such as Mexico and Central America, and more recently migration form South American countries such as Argentina and Ecuador to Europe. However, unlike the urbanization of Europe and North America that accompanied its forest conversion in the 18th to 20th centuries,.the precariousness of industrial and service sectors in developing world encourages a risk-aversion stratgegy of maintaining household member occupying the farm. Thus the way urban development proceeds in Latin America will have a huge impact on migration strategies and thus forest cover change dynamics.

From the 1960s through the 1980s, nearly 2% of rural Latin Americans out-migrated annually, exceeding the rates of other regions. Most migrated to cities and, consequently, the region is already almost as urbanized as the developed world with more than half of its residents urbanites. South America developed primate capitals sooner than Central America, and its percentage of population urban (75%) was, in 1994, higher than that of Central America (53%). Nonetheless, a minority of rural out-migrants settled remote rural areas rather than urban or foreign destinations, often to remote forest frontiers where land for farming is readily available. This has been especially evident in areas still rich in forests such as in the Republic of Congo in Africa, and sparsely settled Indonesian islands in Asia. But it is Latin America, particularly South America's Amazon region and the lowland forests of Central America that has experienced the greatest deforestation directly from migrant farmers. This pattern explains the apparently contradictory finding that deforestation has increased even in countries where the rural population has declined in recent years. As frontier lands become consolidated by large commercial agricultural activities, agricultural exensification is driven large scale farming as a response to favorable international markets (e.g., soya bean in the Brazilian Amazon). Still, the initial forest clearing for subsistence crops and livestock for small and medium sized farmers still accounts for most forest clearing in Latin America. It is for this reason that we wish to consider the relationship between rural population change, and changes in forestland as mediated through agricultural expansion and agricultural intensification.

Recent population processes in Latin America have been associated with dynamic rural landscape transformations. These processes have left their most salient imprint on the massive conversion of the region's forests to agriculture. Indeed, while North America has experienced forest regeneration with the increasing efficiency of farming techniques and a declining rural population working the land, Latin America's forests have atrophied rapidly.[1] While most of this forest clearing occurred in the Amazon region of South America, the world's highest *rates* of forest clearing were dominated by Central America nations.

Latin America harbors the greatest area of closed tropical forests in the world, with Brazil alone containing a third of the world's tropical forests. The Amazon basin also contains 45% of all the fresh water on the Earth, and is the planet's largest carbon sink. Its preservation is thought to be crucial for moderating global warming and regulating global weather systems (Adger, 1994; Tinker, 1996). It also contains the most biologically diverse forests on the planet along its western flank where it hugs the Andes mountain chain. Such great biodiversity is a potential goldmine for the development of medical cures, and new genes for enhancing food production (Wilson, 1992). Yet Latin Americans have been clearing much more forest than people in other regions: During the first half of the 1990s, Latin Americans deforested five times more forest per rural person as Africans and 40 times more than Asians (derived from data in FAO, 1997). Furthermore, reforestation has only minimally compensated for forest losses in Latin America, and far less than in other regions; in the Asia-Pacific region reforestation compensated for over 50% of the forest loss from 1981 to 1992 compared to 6% in Latin America (FAO, 1997).

In this paper we examine what the linkages may be between changes in population, agricultural land use and the environment in Latin America. The next section considers theoretical aspects of the relationships between trends in population, deforestation, and agricultural change. A distinction between the two regions should be noted: Central American nations tend to be much smaller, have much less forest, a much greater *rate* of deforestation, and greater rural population densities than South American nations. Therefore, Central America and South America will be treated separately. Following the regional comparison, a summary of some local-level field studies will be presented to illustrate the wide variability of relationships between population change and land use change and the key roles played by macro-economic, institutional, and contextual factors. Finally we summarize the results and note some gaps in knowledge and the need for more research at the community and farm levels.

METHODS AND HYPOTHESES

Land use data for this paper are derived from the most recent Agricultural Yearbooks of the Food and Agriculture Organization (FAO) of the UN and from FAO online statistical resources. Supplemental sources are also used in areas of questionable data in the tables or for further explanation in the text. Demographic data comes from the United Nations Population Fund 2002 State of the World Population Report, and the FAO Statistics Division. The usual measure of national population density (total population/total land area) ignores the fact that some countries have large areas unusable for agriculture (e.g., mountain ranges, deserts, and urban areas). It also confuses the issue by combining urban and rural populations in the numerator. We

[1] Among the nations of the temperate regions, only Finland and Japan (both at 0.1% annually) reported positive deforestation rates in the second half of the 1990s (World Development Indicators, 2000). In contrast, all tropical nations are experiencing deforestion at a rate of 0.5% or greater annually.

therefore use *rural population density* (rural population per unit of arable land plus land under permanent crops), as a key measure for analyzing potential population impacts on agricultural change and forest cover change. The numerator is modified through population change (rural fertility, rural mortality, and net internal migration between rural and urban areas), while the denominator is affected by changes in the amount of arable and permanently cropped land, which occurs as more land is brought into agricultural use. Thus, if deforestation exceeds rural population growth, rural population density decreases. Conversely, if rural population density increases, whether deforestation increases or not, agricultural intensification must occur if production is to be maintained or increased. Some of the ways agricultural intensification can be achieved include shortening fallow rotations, increasing the temporal and spatial cropping density, and applying irrigated water, fertilizers, insecticides, or herbicides. In this paper we use irrigation and fertilizer use as measures of intensification. No data exists at the regional level for fallow rotations and cropping density while fertilizer use is a good proxy for the use of other inputs.

There are certain relationships that should emerge if rural population is exerting an influence on forest cover change. The most intuitive and expectation from the data is a positive relationship between overall rural population change and change in forestland. Secondly, given similar land size, we would also expect that countries of higher and faster growing rural population and population density will have cleared less *absolute* amounts of forest, and will have deforested at greater rates but will have clear less forest *per rural dweller* than countries with lower and slower growing (or declining) rural population density. These relations are anticipated as the Latin American countries of highest population density have relatively small forestland remaining while they are also the more rural countries with faster population growth. This is intuitive or perhaps even tautological because if rural population density is high it is less likely that there are large unclaimed tracts of forest available to rural farmers – otherwise they would be cleared the land already.

In regards to the relationship between rural population and agricultural land use, we expect countries with high absolute changes in rural population to be associated with greater amounts of absolute increases in agricultural land. However, we also expect that countries of high and growing rural population density will favor a greater cropland/pasture land ratio than countries with lower rural population densities. In Central America, livestock expansion is limited by land availability, especially given the needs of growing rural populations to feed themselves with more land-efficient grains. Further, countries of highest population growth are the ones with the largest rural populations and the great majority of rural inhabitants in Latin America work in agriculture and these countries will be poorer, less urbanized and therefore have less demand for meat. Lastly, we expect that countries with high rural population density will compensate for constraints in land expansion through intensifying agricultural production with fertilizers and irrigation, thus reducing the amount of deforestation per rural person. Conversely, countries of low population density will be more likely to expand cropland rather than intensify its production as a response to increasing rural population density.

Starting in the 1950s, international agencies promoted technological advances in agriculture in developing countries in what became known as the Green Revolution. During these years, new seeds were developed for basic grains, and irrigation, pesticide and fertilizer use all grew dramatically. Most of the growth in agricultural production of the past thirty years is attributable to increases in yields per hectare: From 1961 to 1996 global cereal yields increased 107% while the area harvested increased by only 10% (Bender and Smith, 1997). Only in Latin America has the expansion of the agricultural land area been an important contributor to the expansion of agricultural output, but its share has been declining, and is now less than that of increases in yields.

Both the greater increase in cropland, and the greater increase in intensification in nations of higher rural population density can be better understood through rural and urban population change. In areas of increasing rural population density, increasing cropland is a response to a greater demand for food production to satisfy rural household food requirements. Conversely, in more urbanized countries, meat consumption per capita is much higher, suggesting the need to augment pastureland (FAO, 1998). We hope that examining the consistencies and inconsistencies between these hypotheses and empirical data will improve our understanding of how future trends in forest cover change in Latin America may be related to rural population and agricultural change. This is important both for watershed and soil conservation for the wellbeing of rural populations as well as for the conservation of Central America's biodiverse-rich forests. Since the nations of Central and South America are generally very different in size, rural population density, and in forest endowments, we will treat the two regions separately, starting with Central America.

RURAL POPULATION AND LANDSCAPE CHANGE
CENTRAL AMERICA

We present data for rural population, percent rural, and rural population density in 1961 and 2001, as well as total forest cover and percent of land in forest for the two dates. In Central America from 1961 to 2001 the rural population increased by roughly 19 million or 59%. Rural population density increased rapidly, at an overall rate of 34%. From 1961 to 2001, just under 13 million hectares of forest were cleared, over 15% of the region's 1961 forest cover. There were some drastic variations between the countries themselves regarding trends in forest change over this period. For example, Mexico experienced a drastic decrease in forest cover between the years 1961 and 1981, with an overall loss of 19% of its 1961 forest cover. However, from 1981 to 2000 Mexico experienced a 7.6 million hectare increase in forest cover, making the total amount of forest cleared from 1961 to 2000 just over 3.6 million hectares. Other Central American countries that experienced increases in forest cover in the period from 1981-2000 were Costa Rica, the Dominican Republic, and Honduras with overall increases of 60,000 hectares, 713,000, and 1.4 million hectares respectively. Regarding shifts in rural population, Mexico experienced a 21% increase in rural population density change from 1961 to 2001; a relatively low percentage compared to other much higher levels of rural population density change in the region. Similarly, the Dominican Republic underwent a 22% decrease in rural population density over this period (Appendix).

This deforestation came mainly as a result of changes in rural land use, principally crops and pasture. From 1961 to 2001, the amount of pastureland in Central America increased by 10 million hectares, or 12%. This growth in pastureland was accompanied by an 18% increase in arable and permanently cropped land, representing 5.8 million hectares. In terms of forestland change throughout the time period in relation to rural population density, a drastic decrease in forest cover from 1961 to 1981 at a rate of 21% was accompanied by a heavy increase in rural population density at a rate of 34%. During the previous two decades (1981 to 2000) reforestation has been observed in some countries as rural population density has declined (Haiti being the only exception) due to falling fertility and continued high rates of out-migration. Ultimately, however, the period of 1961-2001 demonstrates drastic levels of deforestation and increased rural population density in Central America, with the overall deforestation rate in the region reaching 15% and rural population density increasing 34% over the entire period.

Most of the forest was converted to cropland and pastureland, which increased an average of 16% among the Central American nations to represent over half of the entire land cover of the region in 2001 (Appendix). Significant cropland expansion occurred, and kept pace with growth in pastureland, particularly in countries of higher population density due to the relatively large portion of land dedicated to subsistence.

Our hypothesis of a positive relationship between rural population density and agricultural intensification was not supported by the data. The percentage of land irrigated rose from 10% to 19% in Central America. Similarly, Central America's fertilizer increased nine times from 30.5 metric tons in 1961 to 285.5 thousand metric tons in 2001. However, the countries with the most intensive land use in terms of irrigation and fertilizer use were not those with the highest rural population densities or the most rapidly growing populations, but rather those with the greater financial wherewithal to afford such measures.

The rest of this section will go into greater detail on relationships between rural population, agricultural land use, and deforestation at the national level. In terms of land use, countries of higher population density tended to have a greater amount of land in cropland relative to pastureland.

Among the countries of highest population density, we should distinguish between Guatemala and Costa Rica which, still today, have millions of hectares of forestland, and Haiti and El Salvador, which had already cleared virtually all but a couple hundred thousand hectares of their woodland by 1966. The first two countries of high rural population density and significant amounts of forestland remaining experienced both high rates and absolute amounts of deforestation and the greatest percentage expansion of both cropland and pastureland in the region by far. Between 1961 and 2001 nearly 50% of the total national territory of both nations was deforested. Guatemala cleared 49% of its forests, while the rural population ballooned by 156%. At over 7% per annum, the deforestation rate of Costa Rica during the 1970s was nearly the highest in the world (surpassed possibly only by Thailand), with the result that much of its forest loss was experienced during that single decade. Guatemala led the region in agricultural expansion. Pastureland mushroomed 167% accompanied by a 46% increase in arable and permanently cropped land and pastureland from 1981-2001. Incredibly, rural population growth still outpaced the expansion of cropland, and, as a result, rural population density increased from 1.79 to 3.69 persons per hectare of agricultural land over the forty-year period.

Conversely the two countries with high population density but scarce remaining forest reserves cleared a fraction of the absolute amount of forest of Guatemala and Costa Rica. El Salvador cleared 57% more than Haiti. Similarly, the countries with the greatest percentage of forest loss had the lowest absolute amount of forest cleared and the lowest amount of forest cleared per rural dweller. Haiti cleared less than 10% the woodland of the average farmer in Central America, while their absolute forest loss was less than 5% the average for Central American nations. In these nations absolute deforestation has declined and will continue in decline as there is little left to clear. With little possibility for further agricultural expansion in these countries, we would expect greater land and labor intensification, off-farm employment, and out-migration.

As predicted, these countries experienced only slight increases in agricultural land during the period and a loss in pastureland. In El Salvador, pastureland remained at 29% of national territory from 1961 to 1981 and increased by 9% from 1981 to 2001 as population density grew from 2.5 to 2.7 persons per hectare of arable and cropped land. Haiti's rural population density grew 71% from 2.8 to 4.8 persons per hectare of agricultural land. Concomitantly, its agricultural land increased 26% and its land in pasture actually decreased by 3% from 1981-2001. In these countries the usual growth in pastureland may have been constrained by the need to more efficiently use scarce arable land for growing crops to feed growing human populations rather than for cattle.

In terms of agricultural intensification, as mentioned above, the use of fertilizer appeared to be correlated with per capita income rather than with population density. For example, in 1994 the wealthiest country in Central America, Costa Rica (1998 GNP: $2,770) applied 128 thousand metric tons of fertilizers while the poorest, Haiti (1998 GNP: $410), used under 14 thousand. Similarly, Costa Rica was second to Mexico in percentage of cropland irrigated, while the poorer countries, such as Haiti and Guatemala had relatively low levels of irrigation. This finding is problematic, of course, since the need for agricultural intensification is greater in poorer countries. The same relationship was found among countries of lower rural population density. Mexico led these countries in fertilizer use and in irrigation while the poorer nations such as Nicaragua and Honduras had relatively little agricultural intensification.

Among Central American nations, from 1961 to 2001 Nicaragua's rural population increased at a rate of 29%, and Guatemala's rural population density almost doubled from 1.79 to 3.69 persons per hectare as rural out-migration and forest clearing outpaced natural population growth. More than 50% of the total national territory was deforested in Nicaragua. Nicaragua and Guatemala were accompanied by Costa Rica in having forest endowments greater than 3 million hectares in 1961 and having cleared forest per rural person at rates substantially higher with other less rurally populated countries. Following Mexico in terms of absolute forest cleared from 1961-2000 was Nicaragua at 3.4million hectares—a figure actually comparable to Mexico's forest loss during the same period. In countries of lower population density, pasture land either already represented a substantial proportion of national territory in 1916 (as was the case of Mexico at 39%), or pastureland growth was among the highest in the region. For example, Panama had a 32% increase of pastureland with a growth in rural population density of 1.2 to 1.8 persons while Nicaragua increased its land in pasture from 32% to 40%.

Mexico resembles the larger South American nations in size and forest resources and we expect relationships with rural population and forest cover change to reflect these characteristics. Mexico harbored approximately three-fourths of all woodland and half the rural population of the region throughout the time period. Despite a large base, Mexico's rural population still grew by 39% from 1961 to 2001. Over three fourths of all woodlands are in Mexico. With such a large forest endowment, Mexico's rural population density was the lowest of all Central American Nations. In fact, its 1961 rural population density was lower than South America's 1961 average of 0.9.

SOUTH AMERICA

In contrast to Central America, in South America, earlier and greater rates of rural-urban migration, and earlier fertility decline together combined to result in a decrease in rural population density from .92 to .51 persons per hectare and rural population fell 6% to 62 million (Appendix). Despite a decline in population pressures; over 52 million hectares were cleared during the period from 1961 to 2001. As a nation, Brazil accounted for about 37% of the regions' forest clearing during this time. The percentage of forests cleared in South America was 6%, though this percentage is deceiving because of the large forest base of the Amazon in Brazil; most countries deforested a much greater percentage of their forests as reflected in the weighted deforestation average of 12% for the region (Appendix).

As illustrated in Figure 4b, two types of countries are evident in South America. In Ecuador especially, but also in Colombia and Bolivia, rural population growth was associated with sharp forest declines. Conversely, the developed nations of the southern cone, Argentina and Chile, as well as Venezuela and Brazil experienced significant deforestation despite decreasing rural populations. Again, pasture expansion appears to explain much of the deforestation in all of these countries except Argentina where widespread land degradation has led to land abandonment and the need to convert forestland to agricultural use (Appendix).

This deforestation came mainly as a result of changes in rural land use, principally crops and pasture. For the South American region as a whole, from 1961 to 2001 rural population decreased by roughly 3 million or 6% (Appendix), due to the high levels of out-migration mentioned earlier. From 1961 to 2001, just over one million hectares of forest were cleared, which composed over 6% of the region's 1961 forest cover. Rural population density declined at an average rate of 19. (Appendix)

Conversely, as in Central America, it would appear that fertilizer use was exogenous to population density given only modest demographic pressures in the region. Fertilizer use rose rapidly from a low level of 54 thousand metric tons in 1961 to 1.2 million metric tons (metric tons is correct?) in 2001. With far greater possibilities for agricultural expansion, in South America relative wealth explains much of the difference in fertilizer use. A relatively wealthy country, Argentina (1998 GNP: $2,470), applied the greatest amount of fertilizers to its cropland (860 thousand mt), while the poorest South American nation, Bolivia (1998 GNP: $1,010), applied the least (12 thousand mt) amount. The wealthier countries in the region, on the southern cone, possess the most fertile soils on the continent and low rural population densities, and thus do not require heavy fertilizer applications. Yet some countries, such as Ecuador, Colombia, and Paraguay, may be starting to experience demographic pressures on diminishing forest resources and exhausted soils. Irrigation rose slowly in the region and advanced more rapidly only in Ecuador, Chile, and Colombia over the period of 1961 to 2001. In the case of Ecuador and

Colombia, perhaps rural population pressure was a factor in intensifying irrigation, though in Chile it was more likely due to the expansion of export agriculture on arid lands. In sum, the expectation stated earlier that (excluding pastureland) increased food production would come disproportionately from agricultural intensification is supported by the data.

In comparing the South American nations, as observed in Central America, there is evidence that the countries of highest population density cleared less forest per capita, cleared less absolute forest, but had higher percentage forest change between the two time periods. Of the four countries of highest population density, all were among the bottom four in the region in forest cleared per rural population, and in absolute forest change (Colombia). These three countries (along with Paraguay) all had 1 to 2 people per arable and cropped land throughout the period, with the exception of Colombia, whose rural population density increased to 2.47 by 2001. Conversely, countries with fewer than 1 person per hectare on average during the time period were Paraguay, Brazil, Chile, and Argentina.

Similarly to Central America, land intensification in the form of land irrigation and the use of fertilizers appeared to be more correlated with investment in export agriculture than in small farmer responses to population pressures. However, unlike Central America, countries of higher population density did not necessarily have a greater proportion of cropland relative to countries of lower population density. This may be due to the fact that all of the South American nations have ample forestland to convert to pasture so that population density may not be a prohibitive factor to pasture expansion. The rest of this section will consider these relationships at the country level for these two clusters of countries.

With the highest rural population density in the region, Ecuador scarcely cleared more than the country of least absolute deforestation in the region, Chile, while Colombia, with a much greater rural population density, was second only to Brazil and Argentina. Still, with a smaller forest base, Ecuador increased its arable and permanently cropped land 17% accompanied by a comparable increase in pastureland). Much of the expansion of cattle in Ecuador has been a consequence of spontaneously expanding frontiers in the Amazon region of that nation (Pichón, 1997). Similarly, much of the expansion in Colombia is due to pasture expansion which ballooned 34% to 40% of the national land cover.

Bolivia and Venezuela trailed only Columbia and Ecuador in rural population density and only Venezuela underwent 26% reforestation from 1961 to 2001, where forest per rural person increased approximately 19% during this time. The absolute amount of forest cleared is particularly low in these countries compared to the regional average. Paraguay also experienced an 8% increase in forest cover over the same period. Deforestation was relatively low while absolute forest cleared was relatively high in the larger Bolivia. Again, we see the important role of pasture in the difference between these two countries.

In Argentina and Venezuela, rural populations declined notably but heavy deforestation continued in Argentina (Appendix). Absolute forest change was consistent with the forest endowments of the countries, with Venezuela increasing its forest cover and Argentina being only second to Brazil in absolute forest loss. In the southern cone nations, an increase in export agriculture in Chile and in land degradation in Argentina were major factors in deforestation considering pastureland decreased and cropland remained static. Tree plantations for paper, pulp, and construction materials—the result of growth in consumer demand from developed countries rather than population growth—also contributed to this increase. By 1995, Chile and Argentina had 1.6 and .8 million hectares, respectively, in tree plantations and many other hectares were being logged without reforestation (Cubbage et al., 1996). Venezuela is an anomalous case.

Lastly, over the four decades (1961 to 2000), Brazil had the lowest percentage rate of deforestation in Latin America (3%), while at the same time its rural population declined by 66% from 1961 to 2001. Brazil's rural population density was under .47 persons per hectare in 2001 and the forest clearing per hectare was the lowest in the region. But at over 19 million hectares **,** its area of forest loss, primarily in the Amazon basin, far exceeded that of any country in the world. Land speculation and pasture expansion was driving much of the deforestation in recent decades in that country's Amazon region (see the discussion that follows on page 37).

DISCUSSION

Despite some notable country-to-country variation in the trends discussed here, some patterns do emerge that suggest a link between rural population and forest clearing for agriculture at the regional level. First, in the South American nations and in Mexico, countries of relatively low rural population densities, the level of deforestation is lower, but the rate of deforestation *per capita* is higher compared with Central American nations with higher densities. On a global scale, the same comparisons hold for Latin America relative to Asia.). Conversely, the Central American nations, countries of higher rural population densities (e.g., Haiti and El Salvador) deforested their land earlier and at higher rates. Deforestation rates remain high because of a shrinking base, but these countries have increasingly lower deforestation rates *per rural dweller* as forest reserves approach extinction. Second, pasture land uniformly accounts for a greater proportion of the total agricultural land than does cropland, and its share has risen in recent decades; this is particularly the case in countries of lower population density (e.g., in South America).

The expectation stated earlier that (excluding pastureland) increased food production would come disproportionately from agricultural intensification is supported by the data. Though extensification increased quite dramatically during recent years, intensification contributed to even more of the increase in food production in Latin America.

With most land that could potentially be converted to agriculture either in protected areas or in areas of marginal production capacity, we expect this trend to continue. However, the largest and most rapid land cover change in Latin America is the conversion of forests and cropland to pastureland. This has particularly been the case in South America where the entire increase of land in food production during recent decades has come from pastureland expansion. We have observed at the regional level that deforestation for the conversion of land for both pasture and cropland has continued throughout Latin America despite significant differences in rural population densities. A decrease in the rural population accompanied by agricultural expansion would appear to contradict both Malthusian and Boserupian theories of population-induced land cover change.

To the extent that growth in pasture has occurred at the expense of agricultural land, average plot sizes for farmers producing crops have fallen, squeezing families onto smaller plots, increasingly below subsistence thresholds, and spurring out-migration (see, e.g., Bilsborrow and Stupp, 1988; Stonich, 1993). This has important implications for the supply of and demand for food in the future, since by 2050 food demand is expected to be about 75% greater in Latin America (Bender and Smith, 1997). Lastly, agricultural intensification appears to be exogenous to rural population at the national and regional level. Rather, since poor farmers often cannot afford fertilizers and irrigation infrastructure, countries with greater levels of export agriculture will tend to have higher levels of these forms of intensification.

Evidently, even in countries where rural population density is declining, agricultural frontiers have still expanded. Although rural-urban migration continues to be large and contribute to city growth,[2] *rural-rural migration* is of growing importance, with people migrating from rural areas characterized by high poverty and unequal land distributions to other, more remote, rural areas in search of land to continue agricultural livelihoods. Contrary to what some scholars expect, then, even in countries and areas of overall rural population decline, substantial deforestation can still occur. On the remote frontiers, colonists are pouring in along newly established roads (e.g., Pichón, 1992; Rudel, 1990; Sader, 1997), converting forests to cropland and pastureland. Thus in Ecuador, for example, although many highland communities have lost inhabitants to migration to Quito, many other migrants have left the densely populated highlands for the Amazon frontier (see the discussion on pages 36 and 37).

To maintain current food consumption levels per capita in coming decades, Latin America will need to greatly increase food imports or increase domestic production through intensification of current agricultural land and/or through expansion of the land area in food production. In countries where little forest remains, as in many Central American nations, intensification of agriculture will be the main option for increasing domestic food production. On the other hand, among South American nations with large endowments of Amazon jungle, extensification is still occurring on a large scale. But the sustainability of Amazonian agriculture is dubious as most of the region's biomass is rooted in nutrient-impoverished soils (Fearnside, 1987; see also, Buol, 1995).

The continued expansion of pasture may prove increasingly untenable. Especially on Amazonian soils, erosion, compaction, weed intrusion, and declining soil fertility reduce the productivity of pasture grass and thus the viability of raising livestock. Meat is a vastly inefficient producer of calories. There is a 7 to 1 loss of food mass in the conversion of grains to animal flesh (Brown, 1994). Furthermore, since livestock currently receives about three-fourths of its energy needs from foraging and one-sixth from grain, if the productivity of pasture land does not increase to meet growing meat demands, livestock will need to rely more on grain, necessitating an increase in cropland productivity. We therefore expect increasing productivity to come from agricultural intensification, particularly in more population dense nations.

Virtually all of South America's 21% net growth in cleared land over the last three decades of the 20th century was due to the expansion of pasture or other land uses other than cropland. By 1994, South America had five times as much pastureland as cropland. Even in

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[2]Chen *et al*. (1998) find it accounts for about two-fifths of urban population growth in the region, with the rest due to natural population growth (the difference between the fertility and mortality of the urban population).

Central America, the ratio was 3 to 1. Nonetheless, it is important to note that much pastureland in Latin America is converted from cropland rather than from forests directly. This is most clear in the case of Brazil, where although much forestland was cleared for other uses, the total area of forest eliminated from 1966 to 1994 was the same as the growth in pastureland (e.g., Nations, 1997; Hecht and Cockburn, 1990). Below we review land use changes by country.

That Central America amply surpassed South America in use of fertilizer despite lower incomes per capita may well suggest that, with fewer opportunities to extensify cropland due to higher rural population densities and smaller forest frontier areas left to clear, it had to resort earlier to intensification, including the application of fertilizers. Some evidence for Boserupian intensification therefore exists in Central America.

In developing countries, agriculture accounts for 80% of water use (IFPRI, 1996). The growing scarcity of fresh water makes its contribution to increasing agricultural yields limited in much of the world, though this is not a pervasive problem in Latin America. The countries that increased irrigation most were not those with the highest rural population densities or the most rapidly growing populations, but rather those with large export operations on arid lands (viz., Mexico and Peru). Similarly, the use of fertilizer tends to be correlated with per capita income rather than with population density. The wealthier countries in the region, on the southern cone, possess the most fertile soils on the continent and low rural population densities, and thus do not require heavy fertilizer applications.

To maintain current food consumption levels per capita in coming decades, Latin America will need to greatly increase food imports or increase domestic production through intensification of current agricultural land and/or expansion of the land area in food production. In countries where little forest remains, as in many Central American nations, intensification will be the main option for increasing food production. On the other hand, among South American nations with large endowments of Amazon jungle, extensification is still occurring on a large scale, and could continue. But the sustainability of Amazonian agriculture is dubious as most of the region's biomass is rooted in nutrient-impoverished soils (Buol, 1995).

However, regional and country level comparisons conceal great complexities at local scales. It is at the community and household level that economic and demographic decisions are made that generate the population and environment dynamics observed at larger scales. We therefore now turn to a sampling of country studies to explore more direct relationships between population and environment change. As we will discuss in the case studies to follow, the importance of scale and place can be concealed in macro-level analyses: *where* population grows in rural areas, and *how* those populations use the land are much more important determinants of land cover change than overall changes in rural population density *in se*. We now provide three case studies to illustrate how rural population change and land use dynamics are significantly influenced by socio-economic, and political factors operating at multiple scales.

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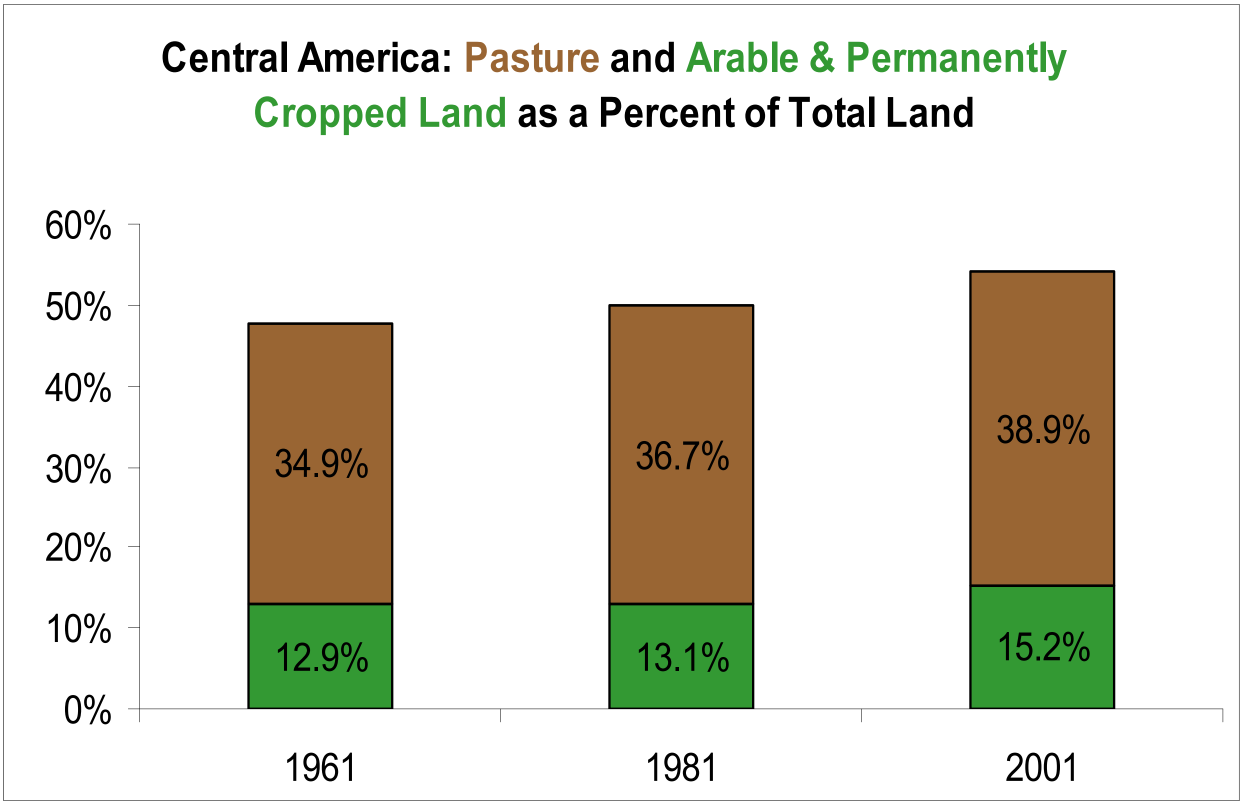
CENTRAL AMERICA

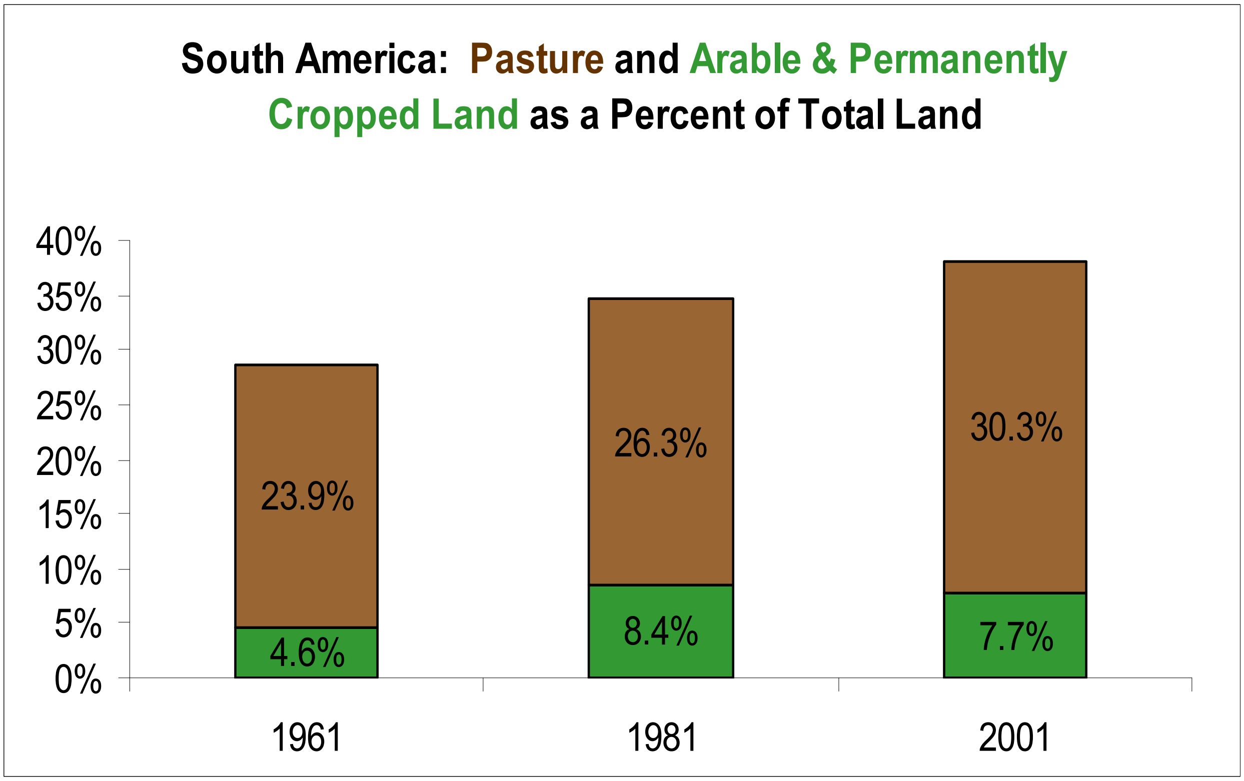
	Rural Population Density		Rural Population Change	Deforestation	Change Forest/Capita	
	1961	1961-2001	1961-2000	1961-2001	1981-2000	1961-2000
Costa Rica	1.76	81%	98%	-45%	-24%	-72%
Dominican Republic	2.32	-22%	26%	100%	109%	59%
El Salvador	2.51	8%	51%	-49%	-17%	-66%
Guatemala	1.79	106%	156%	-49%	-62%	-80%
Haiti	2.81	71%	62%	-51%	-46%	-70%
Honduras	1.02	109%	101%	-11%	5%	-56%
Mexico	0.78	21%	39%	-6%	2%	-32%
Nicaragua	0.81	29%	137%	-51%	-51%	-79%
Panama	1.20	51%	87%	-40%	-47%	-68%



	Percent A&P Land Irrigated			Fertilizer Use (1000 Kg/Ha. of Cropland)		
	1961	*1981*	*2001*	*1961*	*1981*	*2001*
Central America						
Costa Rica	5.42	12.97	20.57	19	72	128
Dominican Republic	11.11	11.93	17.23	14	58	98
El Salvador	2.78	4.97	4.95	21	88	73
Guatemala	2.08	3.98	6.82	15	89	183
Haiti	3.02	7.82	6.82	0	6	14
Honduras	3.38	4.65	5.60	6	28	152
Mexico	12.63	22.17	23.15	191	1561	1870
Nicaragua	1.53	6.37	4.38	4	60	23
Panama	2.48	4.83	5.04	5	30	29
Average	**10.39**	**17.75**	**19.04**	**30**	**222**	**285**

SOUTH AMERICA

	Rural Population Density		Rural Population Change	Deforestation	Change Forest/Capita	
	1961	1961-2001	1961-2000	1961-2001	1981-2000	1961-2000
Argentina	0.19	-34%	-19%	-34%	-39%	-18%
Bolivia	1.49	-32%	47%	-12%	-13%	-40%
Brazil	1.41	-66%	-21%	-3%	20%	23%
Chile	0.64	46%	-12%	-18%	-15%	-7%
Colombia	1.76	40%	20%	-16%	-3%	-30%
Ecuador	1.18	34%	59%	-43%	-35%	-64%
Paraguay	1.50	-48%	101%	8%	-14%	-46%
Venezuela	2.15	-57%	6%	26%	38%	19%



	Percent A&P Land Irrigated			Fertilizer Use (1000 Kg/Ha. of Cropland)		
	1961	***1981***	***2001***	***1961***	***1981***	***2001***
South America						
Argentina	3.45	4.55	4.46	16	96	860
Bolivia	4.99	4.44	4.26	0.8	7	12
Brazil	1.73	2.59	4.38	270	2,753	6,773
Chile	28.02	22.74	82.61	46	114	481
Colombia	4.55	7.43	21.18	71	280	640
Ecuador	17.53	20.65	28.98	11	70	231
Paraguay	3.70	3.09	2.15	0.6	9	67
Venezuela	14.46	8.39	16.87	19	146	300
Average	**4.89**	**4.74**	**7.39**	**54**	**434**	**1,170**