

## Is deforestation accelerating in the Brazilian Amazon?

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### Summary

Recent studies suggest that deforestation rates in the Brazilian Amazon could increase sharply in the future as a result of over US\$40 billion in planned investments in highway paving and major new infrastructure projects in the region. These studies have been challenged by several Brazilian ministries, which assert that recent improvements in environmental laws, enforcement and public attitudes have fundamentally reduced the threat posed to forests by such projects. The notion that hazards to Amazonian forests have declined over the last decade was assessed using available data on deforestation rates from 1978 to 2000. Although the alarmingly high rate of forest loss during 1978–1989 (1.98 million ha yr<sup>-1</sup>) declined somewhat in 1990–1994 (1.38 million ha yr<sup>-1</sup>), it rebounded to a high level in the period 1995–2000 (1.90 million ha yr<sup>-1</sup>). Moreover, correlation and regression analyses reveal that both absolute and per caput rates of forest loss accelerated significantly over the last decade. These trends fail to support the assertion that deforestation pressure in Amazonian forests has been brought under control. Poor enforcement of existing environmental laws, rapidly expanding logging and mining industries, increasing population pressure and other challenges are greatly hindering efforts to limit the environmental impacts of development activities in Brazilian Amazonia.

**Keywords:** Amazon, Brazil, deforestation, development policy, population growth, tropical rain forest

### Introduction

The Brazilian Amazon sustains about 40% of the world's remaining tropical rainforests and plays vital roles in maintaining biodiversity, regional hydrology and climate, and terrestrial carbon storage (Salati & Vose 1984; Phillips *et al.* 1998; Fearnside 1999). Recent studies have raised serious concerns about the future of these forests, as a result of over US\$40 billion in planned investments in new highway paving, railways, gas lines, power lines, hydroelectric reservoirs and other major infrastructure in the region

(Carvalho *et al.* 2001; Laurance *et al.* 2001a). These projects comprise part of *Avanço Brasil* (Advance Brazil), a federal initiative designed to improve energy and transportation networks and accelerate development in the industrial agriculture, timber and mining sectors of the economy.

Most deforestation, logging and forest fires in the Amazon occur in the general vicinity of roads and highways (Fearnside 1986; Laurance 1998; Alves *et al.* 1999; Steininger *et al.* 2001a, b) and two recent studies used remote-sensing data to quantify forest destruction near existing highways (Carvalho *et al.* 2001) or near highways and unpaved roads (Laurance *et al.* 2001a). When conditions were projected 20–25 years in the future, based on expected deforestation from new highways alone (Carvalho *et al.* 2001) or from highways, roads and infrastructure projects (Laurance *et al.* 2001a), the studies concluded that the *Avanço Brasil* programme would sharply increase the rate and spatial extent of forest destruction, especially in remote frontier areas of the basin.

These studies were quickly attacked by several Brazilian ministries (e.g. Amaral 2001; Goidanich 2001; Silveira 2001; Weber 2001), which claimed that a key assumption of both, namely that the past could be used to predict the future in Amazonia, was critically flawed. This was, they asserted, because fundamental changes in Brazilian environmental laws, development policies, enforcement capabilities and public attitudes had occurred over the last decade (Amaral 2001; Goidanich 2001; Silveira 2001; Weber 2001). The ministries argued that these changes would greatly reduce the impacts of new highways and infrastructure projects, relative to the notoriously damaging effects of such projects in the 1970s and 1980s (e.g. Fearnside 1987, 1990; Brown & Pearce 1994; Nepstad *et al.* 1997).

If these assertions are correct, then there exist two logical predictions. First, deforestation rates in the Brazilian Amazon should have been lower in the 1990s than in preceding years, especially if calculated on a per caput basis to adjust for the region's growing population. Second, both absolute and per caput deforestation rates should have declined progressively throughout the 1990s. These trends would be expected if improved environmental laws, policies, enforcement and attitudes were truly altering the status quo in the Amazon. Here we test these predictions using reliable deforestation estimates for the Brazilian Amazon, and discuss the implications of our analysis for forest conservation.

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## Methods

### Estimating deforestation

Among tropical nations, Brazil probably has the world's best monitoring of deforestation activity. These estimates are produced by Brazil's National Institute for Space Research (INPE) for the entire Brazilian Legal Amazon (Fig. 1) by visually interpreting satellite imagery from the Landsat Thematic Mapper (e.g. INPE 1998, 2000). The estimates have been produced annually since 1988, although only a single estimate was derived for 1992–1993. The most recent annual estimate, for the year 2000, is still preliminary, based on sampling the most heavily deforested parts of the region. In previous years, these preliminary values have been very close to the final deforestation estimate (<5% difference).

INPE's (1998, 2000) deforestation data are generally well-regarded scientifically, and are intermediate between estimates produced by a computerized classification of remote-sensing imagery (Houghton *et al.* 2000) and those reported by the United Nations Food and Agricultural Organization (FAO 1993; see Fearnside 2000a for a critique of the FAO estimates). Overall, the INPE data may underestimate the total anthropogenic impact on Amazonian forests. First, small (<6.25 ha) clearings are not included in the INPE estimates. Second, the INPE (1998, 2000) method fails to detect environmental changes that do not cause a major loss of forest canopy cover, such as selective logging, surface fires, edge effects, small-scale mining and overhunting (Skole & Tucker 1993; Laurance 1998; Cochrane *et al.* 1999; Nepstad *et al.* 1999a). Their repeated assessments do, however, facilitate the discrimination of most regrowth from primary forest, which can be problematic in shorter-term studies using remote-sensing data. Finally, in some years

cloud cover may have obscured certain Landsat scenes used by INPE, causing deforestation to be underestimated (Fearnside 1997).

In addition to the annual deforestation data from INPE, an average deforestation estimate for the 1978–1988 interval was obtained from Fearnside (1993a, 1997), who evaluated independent assessments of deforestation over this period by INPE (Fearnside *et al.* 1990) and Skole and Tucker (1993). Both of these studies compared imagery from different satellites, the Landsat Multispectral Scanner in 1978 and the Landsat Thematic Mapper in 1988. Fearnside (1993a, 1997) combined the best features of both estimates, incorporating improved data on original forest cover, correcting for the misclassification of older secondary forests and including data on forests flooded by hydroelectric dams.

Deforestation rates sometimes varied considerably among years and were often not normally distributed, and we therefore used both parametric and nonparametric comparisons. For parametric tests, deforestation data were log-transformed prior to analysis to improve normality and minimize heteroscedasticity.

### Amazonian population growth

Because deforestation rates may be influenced by the size of the Amazonian population, we obtained census data for the Brazilian Legal Amazon. These data have been collected at approximately decadal intervals (1970, 1980, 1991, 2000) by the Brazilian Institute for Geography and Statistics (e.g. IBGE 2000). To enumerate the population of the Legal Amazon, we summed data for the nine individual Amazonian states (Fig. 1) for each census, excluding areas of Mato Grosso and Maranhão that fell outside the Legal Amazon's boundaries. Data for rural and urban populations were calculated separately. In Brazil's national censuses, urban areas are defined as those that are annexed by each legally incorporated city (C. Fischer, Amazonas State Environment Department [IPAAM], personal communication 2001). In a few cases, data were not collected consistently across all states and censuses (e.g. rural versus urban populations were not counted separately in Acre in 1970), and were necessarily estimated by extrapolating from subsequent censuses, but this had little effect on overall population trends.

Because populations tend to grow geometrically, rather than linearly, we calculated the mean growth rate (%/yr) for each decadal interval using a logarithmic model (Sheil *et al.* 1995):

$$\text{Annual growth} = \left[ 1 - \left( \frac{N_t}{N_o} \right)^{1/t} \right] \times 100 \quad (1)$$

where  $N_t$  = population size at the end of the interval,  $N_o$  = population size at the beginning of the interval and  $t$  = number of years. The annual growth rate was then used to estimate the population size of the Legal Amazon by interpolation for successive years between the decadal censuses.

Finally, the population data were used to estimate per caput



**Figure 1** Boundaries of the Brazilian Legal Amazon and its states (AC = Acre; AM = Amazonas; AP = Amapá; MA = Maranhão; MT = Mato Grosso; PA = Pará; RO = Rondônia; RR = Roraima; TO = Tocantins).

deforestation rates for each year, by dividing the annual deforestation rate by the estimated size of the rural population. Although urban populations also influence regional deforestation (Browder & Godfrey 1997), rural populations are directly responsible for most deforestation and are considered a more effective indicator of population pressure on forests (Wood & Skole 1998; Imbernon 2000; P.M. Fearnside, National Institute for Amazonian Research [INPA], personal communication 2001; W.F. Laurance, A.K.M. Albernaz, G. Schroth, P.M. Fearnside, S. Bergen, E.M. Venticinque & C. Da Costa, unpublished work 2001). Roughly 70% of deforestation in Brazilian Amazonia is attributed to cattle ranchers on medium to large properties (Fearnside 1993b; Nepstad *et al.* 1999b), and there are also at least 500,000 small farmers in the region, each of whom clears an average of 1 ha of forest per year (Homma *et al.* 1992). The relatively important role of rural populations is suggested by a recent study which demonstrates that, at two spatial scales of analysis, rural population density was a better predictor of local deforestation in Brazilian Amazonia than was urban population size (W.F. Laurance, A.K.M. Albernaz, G. Schroth, P.M. Fearnside, S. Bergen, E.M. Venticinque & C. Da Costa, unpublished work 2001). Temporal trends in per caput deforestation rates were assessed using regression and correlation analyses.

## Results

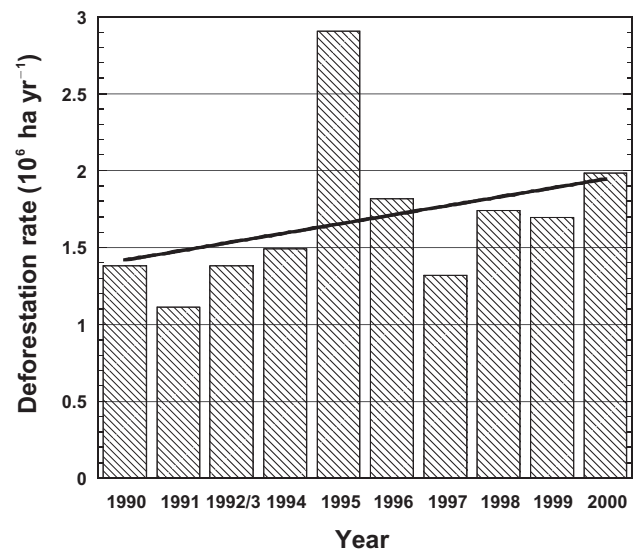
### Did deforestation rates decline in the 1990s relative to previous years?

Including forest flooded by hydroelectric dams, total estimated deforestation in the Brazilian Legal Amazon was 169.9 million ha by January 1978, and 401.4 million ha by August 1989 (Fearnside & Ferraz 1995). Over this 11.67-year interval, the mean annual deforestation rate was very high, averaging 1.984 million ha yr<sup>-1</sup>.

During the 1990–2000 interval, deforestation rates declined somewhat, averaging  $1.654 \pm 0.464$  million ha yr<sup>-1</sup>. There was, however, a substantial difference in deforestation between the first and second halves of the decade. From 1990 to 1994, deforestation averaged only  $1.348 \pm 0.125$  million ha yr<sup>-1</sup>, but this rate rose substantially during 1995–2000 to  $1.901 \pm 0.488$  million ha yr<sup>-1</sup>. It is impossible to compare deforestation rates from 1978–1989 with those from 1990–1994 and 1995–2000 statistically, because the 1978–1989 value is a single number, lacking a variance estimate. It appears, nevertheless, that mean deforestation rates were quite similar in the 1978–1989 (1.984 million ha yr<sup>-1</sup>) and 1995–2000 (1.901 million ha yr<sup>-1</sup>) intervals, with a temporary decline in 1990–1994 (1.384 million ha yr<sup>-1</sup>).

### Did deforestation rates decline over the last decade?

Deforestation rates not only failed to slow over the last decade, but they increased significantly (Fig. 2). For example, when the 1990–1994 and 1995–2000 intervals were compared, the latter had a significantly higher rate of defor-



**Figure 2** Annual estimates of deforestation in Brazilian Amazonia from 1990 to 2000. The fitted regression line shows the overall trend.

estation, both when parametric (one-tailed *t*-test, d.f. = 8,  $t = -2.34$ ,  $p = 0.024$ ) and non-parametric (one-tailed Mann-Whitney *U*-test,  $p = 0.017$ ) tests were used.

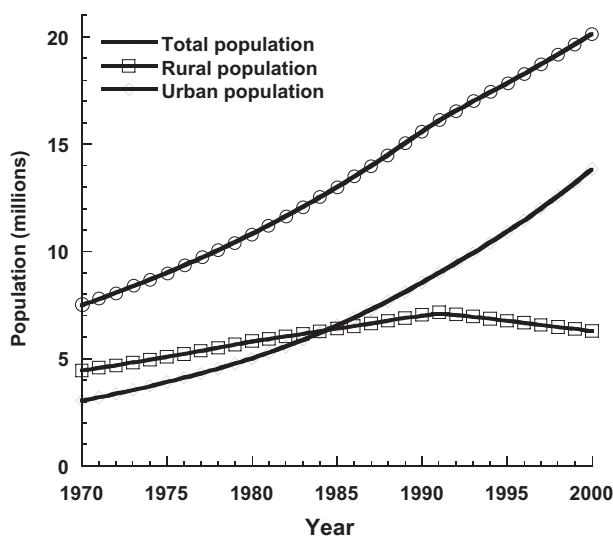
Correlation and regression analyses were also used to assess trends in deforestation over the 1990–2000 interval (the same deforestation value was used for 1992 and 1993, which had a composite estimate). A conservative non-parametric test suggested that deforestation rates increased over time, although the test was marginally non-significant (Spearman rank correlation,  $n = 11$ ,  $r_s = 0.571$ ,  $p = 0.067$ ). When linear regressions were used, the analysis was non-significant ( $R^2 = 25.2\%$ ,  $F_{1,9} = 3.03$ ,  $p = 0.116$ ) only because deforestation rose so dramatically in 1995. When this outlier was removed, there was a highly significant relationship between time and deforestation rate ( $R^2 = 60.7\%$ ,  $F_{1,8} = 12.35$ ,  $p = 0.008$ ). These analyses suggest that rates of deforestation increased progressively over the last decade, with a striking peak in 1995.

### Have per caput deforestation rates declined?

The population of the Brazilian Amazon grew rapidly over the last three decades, increasing from about 7.5 million in 1970 to over 20 million in 2000 (Table 1, Fig. 3). This translates into a mean annual growth rate of 3.35%, compared to 1.88% for the remainder of Brazil over the same interval. Urban populations grew especially quickly, by an average of 5.18% per year, both via the expansion of existing cities and legal incorporation of new cities (cf. Browder & Godfrey 1997). Amazonia's rural population grew more slowly, by 2.71% per year in the 1970s and 1.92% per year in the 1980s, and then actually declined in the 1990s by 1.44% per year. This resulted in a net average growth of 1.18% per year for the rural population over the last three decades (Table 1).

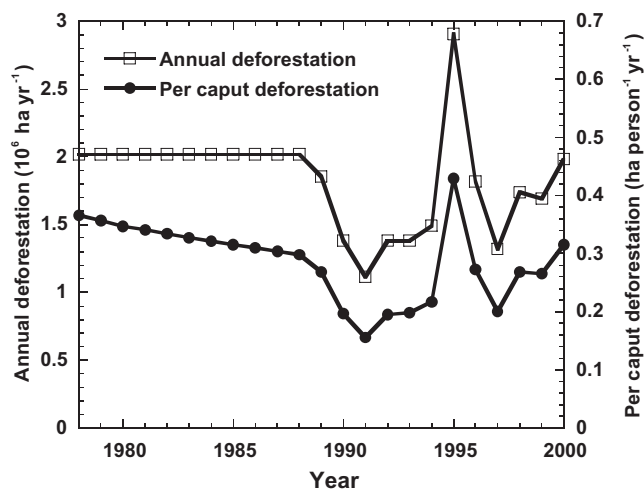
**Table 1** Size of rural and urban populations in the Brazilian Legal Amazon from 1970 to 2000, compared to the remainder of Brazil and the country as a whole. Also shown is the net percentage change and annual population growth for each census interval.

Year or interval	Amazon			Brazil excluding Amazon	Brazil overall
	Rural	Urban	Overall		
<i>Population size (millions)</i>					
1970	4.450	3.046	7.496	85.643	93.139
1980	5.813	5.002	10.815	110.336	121.151
1991	7.168	9.014	16.182	130.643	146.825
2000	6.291	13.848	20.139	149.452	169.591
<i>Net percentage change per census interval</i>					
1970–1980	30.63	64.22	44.28	28.83	30.08
1980–1991	23.31	80.21	49.63	18.40	21.19
1991–2000	–12.23	53.63	24.45	14.40	15.51
Mean	13.90	66.02	39.45	20.54	22.26
<i>Annual population growth (% yr<sup>-1</sup>)</i>					
1970–1980	2.71	5.09	3.73	2.57	2.66
1980–1991	1.92	5.50	3.73	1.55	1.76
1991–2000	–1.44	4.89	2.46	1.51	1.61
Mean	1.18	5.18	3.35	1.88	2.02



**Figure 3** Estimated growth of the Amazonian human population from 1978 to 2000, using a logarithmic model to interpolate between decadal censuses.

When per caput deforestation rates (Fig. 4) were compared between the 1978–1989 and 1990–2000 periods, the pattern was similar to that observed for absolute deforestation: the mean rate was very high from 1978–1989 (0.324 ha person<sup>-1</sup> year<sup>-1</sup>), declined from 1990–1994 (0.192 ha person<sup>-1</sup> year<sup>-1</sup>) and then rebounded during 1995–2000 (0.292 ha person<sup>-1</sup> year<sup>-1</sup>). The obvious lack of statistical independence for the 1978–1989 observations (partially based on a single mean estimate for absolute deforestation rate) precludes reliable statistical comparisons because variance estimates for this interval were truncated. Nevertheless,



**Figure 4** Comparison of absolute and per caput (based on the estimated size of the rural population) deforestation rates in the Brazilian Amazon from 1978 to 2000.

the fact that there was no significant difference between the 1978–1989 and 1995–2000 intervals (*t*-tests with both raw and log-transformed data,  $p > 0.27$ ) indicates that per caput deforestation rates during these periods were not dissimilar, because the likelihood of obtaining a significant difference should have increased with reduced variances for the earlier interval.

During the 1990s, per caput deforestation rates rose significantly (Fig. 4). There was a highly significant difference between the 1990–1994 and 1995–2000 intervals, using both parametric (one-tailed *t*-test, d.f. = 9,  $t = -3.21$ ,

$p = 0.0054$ ) and non-parametric (one-tailed Mann-Whitney  $U$ -test,  $p = 0.022$ ) methods. There also was a highly significant correlation between year and per caput deforestation rate using a non-parametric test (Spearman rank correlation,  $n = 11$ ,  $r_s = 0.746$ ,  $p = 0.0085$ ). A linear regression analysis was non-significant when all years were included ( $F_{1,9} = 3.30$ ,  $p = 0.103$ ), but was highly significant when the 1995 outlier was removed ( $F_{1,8} = 20.90$ ,  $p = 0.0018$ ). Thus, even when adjusted for the changing size of the rural population, deforestation rates in Brazilian Amazonia increased significantly over the last decade.

## Discussion

These analyses fail to support the notion that deforestation pressures have been substantially reduced in the Brazilian Amazon. Rather, the alarmingly high pace of forest loss in the years 1978–1989 declined somewhat in the early 1990s, but rebounded to similarly high levels during 1995–2000. Both absolute and per caput deforestation rates accelerated significantly over the last decade, with the average rate of forest loss in 1995–2000 being equivalent to more than 3.6 ha per minute. These trends are obviously at variance with recent assertions by some Brazilian ministries (e.g. Amaral 2001; Goidanich 2001; Silveira 2001; Weber 2001), that threats to Amazonian forests have declined markedly in recent years because of fundamental changes in environmental legislation, policies, enforcement and public attitudes.

The general deforestation trends that we identified are superimposed on considerable variations among years, partly in response to economic factors. For example, deforestation was exceptionally low in 1991 because Brazilian bank accounts were frozen in the preceding year, stifling investment and economic activity. The dramatic jump in deforestation in 1995 occurred because available investment funds rose sharply following government economic reforms that stabilized the Brazilian currency (Fearnside 1999, 2000b). Increased economic activity has also been cited as a reason for rising deforestation in 2000 (Bugge 2001). Climatic factors, such as periodic El Niño droughts, also influence deforestation by affecting the size and frequency of purposeful and accidental forest fires (Cochrane & Schulze 1998; Nepstad *et al.* 1998; Barbosa & Fearnside 1999).

In addition to varying temporally, the spatial patterns of deforestation have changed in recent decades. In the 1990s, for example, deforestation surged in Mato Grosso and Rondônia, and also increased in Amazonas, Amapá and Roraima, relative to the preceding decade. Deforestation rates in the 1990s fell slightly in Pará, Maranhão and Tocantins, compared to the 1980s, but were still very high in these states (Fearnside 1997).

In Brazil, there have in fact been laudable improvements in environmental legislation and public awareness, so why has this not translated into permanent reductions in deforestation rates? Perhaps the single biggest reason is that enforcement capabilities lag far behind current legislation. In

fact, illegal deforestation, logging, mining, hunting and animal-trading activities are rampant in the Amazonian frontier (Fearnside 1990; Laurance 1998, 2000). Brazil's national security agency (SAE) estimates that 80% of all timber cutting in the Amazon is illegal, with no environmental control or collection of government royalties, and recent raids have netted massive stocks of stolen timber (Abramovitz 1998). There is, moreover, little evidence that legislation designed to limit deforestation on private properties is being enforced (Alves *et al.* 1999; Imbernon 2000). A large effort to reduce illegal activities in Amazonia was recently initiated by Brazil's national environmental agency (IBAMA), but its effectiveness may be limited because the planned sweeps were trumpeted in local newspapers prior to being implemented (e.g. Anon. 2001a). Corruption of some enforcement officials is another chronic problem; for example, three IBAMA inspectors were recently filmed extorting a bribe from a timber company official in order to drop a large fine imposed for illegal logging (Anon. 2000).

It is clear that improved enforcement could have a major impact on environmental management in the Brazilian Amazon. One notable success has been a recent reduction in forest burning in states such as Mato Grosso and Pará, which have traditionally had heavy deforestation activity. In the past, temporary government bans on burning have had little effect, but more vigorous enforcement in 2000–2001 and governmental (Anon. 1998) and private (Anon. 1999) initiatives to train local communities in fire-control methods have demonstrated that substantial reductions in forest burning can be achieved. Nevertheless, the prevalence of fire-dependent agriculture in the Amazon, particularly cattle ranching and slash-and-burn farming, means that controlling forest burning will remain a chronic and difficult challenge (Nepstad *et al.* 1999b).

Many other problems contribute to high Amazonian deforestation rates. For instance, while environmental awareness is growing in major cities, especially in southern Brazil, many Amazonian residents and politicians have a strongly pro-development attitude. This has manifold effects on development activities; for example, public hearings for proposed development projects in the Amazon are often poorly attended and rarely have much effect on the projects (Laurance *et al.* 2001b). In addition, the rapid expansion of Amazonian timber and mining industries is promoting deforestation (Fearnside 1990; Nepstad *et al.* 1997) by creating extensive road networks that greatly increase access to forests for colonists, ranchers and hunters (Uhl & Buschbacher 1985; Laurance 2001). Land-use planning in the Amazon is also fraught with problems: it is a confusion of individual zonings by the nine Amazonian states, many of which have been strongly influenced by local resource-users and pressure groups (Anon. 2001b).

Ultimately, the rapid expansion of the Amazonian population, which rose from about 2.5 million in 1960 to over 20 million today (IBGE 2000), is further increasing pressures on forests. Although rural populations declined slightly over the

last decade (reflecting both increased migration into Amazonian cities and the legal incorporation of new cities), the region's overall population is still increasing at a rate nearly twice that of the rest of Brazil. Such dramatic growth has largely resulted from government policies designed to accelerate immigration and economic development in the region, including large-scale colonization schemes, credit and tax incentives to attract private capital, and major transportation projects such as the TransAmazon and Manaus-Boa Vista Highways (Moran 1981; Smith 1982; Fearnside 1987; Goodman & Hall 1990). As a result, the Amazon has the highest rate of immigration of any region in Brazil, and has often been characterized as an 'escape valve' for reducing overcrowding, social tensions and displacement of agricultural workers in other parts of the country (Anon. 2001c). In addition to rapid immigration, existing populations in the region are growing at a high rate. Although average family sizes have declined in recent years, many Amazonian residents begin bearing children at a relatively young age and the population is strongly skewed toward young individuals currently in or entering their reproductive years (Brown & Pearce 1994; Wood & Perz 1996), demographic factors that contribute substantially to rapid population growth (Ehrlich *et al.* 1995).

In summary, there is little empirical support for recent assertions by several Brazilian ministries that changes in environmental laws, policies, enforcement and public attitudes have led to a fundamental reduction in threats to Amazonian forests. The absence of such changes suggests that the Avanço Brasil programme, with its unprecedented investments in highway paving and new infrastructure projects, would substantially increase both the rate and spatial extent of Amazonian deforestation (Carvalho *et al.* 2001; Laurance *et al.* 2001a). By criss-crossing the basin, these projects would open up extensive new frontiers for colonization and encourage further immigration into a region that is already experiencing rapid population growth. These projects are also expected to increase forest fragmentation on a large spatial scale (Laurance *et al.* 2001a), and the resulting forest remnants would be far more vulnerable than intact forests to predatory logging, wildfires and other degrading activities.

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