DEFORESTATION IN BRAZILIAN AMAZONIA: THE EFFECT OF POPULATION AND LAND TENURE

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ABSTRACT

LANDSAT data for 1978, 1988, 1989, 1990 and 1991 indicate that by 1991 the area of forest cleared had reached 426 X 10^3 km^2 (10.5% of the 4 X 10^6 km^2 originally forested portion of Brazil's 5 X 10^6 km^2 Legal Amazon Region). Over the 1978-1988 period, forest was lost at a rate of 22 X 10^3 km^2/yr (including hydroelectric flooding), while the rate was 19 X 10^3 km^2/yr for 1988-1989, 14 X 10^3 km^2/yr for 1989-1990 and 11 X 10^3 km^2 for 1990-1991. The reduction in the rate since 1987 has mostly been due to Brazil's economic recession rather than to any policy changes.

The number of properties censused in each size class explains 74% of the variation in deforestation rate among the nine Amazonian states. Multiple regressions indicate that 30% of the clearing in 1991 can be attributed to small farmers (properties < 100 ha in area), and the remaining 70% to either medium or large ranchers. The social cost reducing deforestation rates would therefore be much less than is implied by frequent pronouncements that blame "poverty" for environmental problems in the region.

ESTIMATES OF DEFORESTATION

Definitions and Techniques

Estimates of the deforestation rate in Brazil's Amazon region over the last few years have varied tremendously. Reliable estimates are needed because of deforestation's contribution to global concerns such as greenhouse warming and loss of biodiversity, as well as its destruction of a potentially valuable resource for maintaining Amazonia's human population.

In order to calculate deforestation rates, one must have estimates of the deforested area at two points in time. The two estimates must use the same criteria in defining the geographical area under consideration, the vegetation within that area (i.e., what is classified as "forest"), and the types of alteration to be counted as "deforestation." Commonly used estimates have been inconsistent in all of these respects, including the delimitation of "Amazonia," the inclusion or exclusion of the cerrado (scrub savanna), consideration of secondary forests as "forest" or "deforested," and the counting of re-clearing secondary forests and of flooding by hydroelectric dams as "deforestation." The great sensitivity of deforestation rate to small changes in the elapsed time interval means that close attention must be paid to the method used for establishing the dates to which the estimates refer. Different satellite orbits between LANDSAT-3 and -5 -- and differences in the ways that results have been reported -- make complete consistency impractical. Nevertheless, substantial improvements over past estimates can be made through attention to such factors as the weighting scheme applied in adjusting the estimates for older images used in locations where cloud cover obscures the ground for the estimate's nominal year, the correction for cloud cover in the deforestation extent estimate for the most recent year, and the treatment of fractional-year differences in image dates (in relation to the seasonal cycle of clearing activity in different parts of the region). Re-examination of the images and overlays has also revealed a number of errors in their original interpretation (measurement of deforested areas) and in the computation of the results, which are corrected in the estimates used here. A detailed description of the deforestation estimates is presented elsewhere (1). Deforestation rates are calculated based on LANDSAT mosaics from 1978, 1988, 1989, 1990 and 1991.

Tardin et al. (2) used black and white images produced by bands 5 and 7 of the LANDSAT-3 satellite's Multispectral Scanner (MSS) at a scale of 1: 500,000 to estimate the extent of deforestation in 1978. MSS has a resolution of 80 m, making it less precise than the 30 m resolution of the Thematic Mapper (TM) sensor carried by the LANDSAT-5 satellite launched in 1984, which

was used in the later studies. LANDSAT-TM images at a scale of 1:250,000 were originally interpreted for 1988 by Tardin and da Cunha (3), and later supplemented by additional images (4, 5) to cover all 229 scenes covering the Legal Amazon. Images in the final mosaic were all color composites of TM bands 3, 4 and 5 (some of the original images were of band 3 in black and white, and have been substituted in the final mosaic used here). The term "image" refers to data recorded for a given scene on a particular date, in this case reproduced on photographic paper for visual interpretation. A "scene" refers to a geographical location at which information is captured and recorded each time the satellite passes overhead (LANDSAT scenes correspond to areas approximately 185 km on a side, designated by coordinates indicating the path and row). The 1989 mosaic originally interpreted by Tardin et al. (2) has been supplemented to cover all 229 scenes (5). All images in the 1990 and 1991 mosaics for which cloud cover permitted interpretation were used for these years. However, not all images are from the nominal years of the estimates because cloud cover invariably leaves some scenes or portions of scenes with no usable image for any given year. Corrections for image dates are included in the rate estimates, but the values for extent of deforestation are the sum of the estimates (including cloud cover corrections) for each existing image (i.e. deforestation extent is not projected forward to a standardized date for each nominal year).

The outlines of clouds were digitized for each image. Correction for cloud cover was done by assuming that deforested area under the clouds is in the same proportion as deforestation in the cloud-free portion of the same image. Locations with clouds in the 1988 data set that were later found to have no deforestation in the 1989 images were classed as intact in 1988. The same procedure has been applied with the 1990 and 1991 data sets, and the area with no coverage has been successively reduced. The locations with greatest cloud cover are in the far northern portion of the region (Amapá and Roraima); fortunately, this is the part of the region with the least deforestation.

The following definitions are adopted uniformly in the present paper. The "Legal Amazon" refers to Brazil's 5 X 10^6 km^2 region covering all or part of nine states (Figure 1). This administrative region (6) is larger than the Amazon River's 4 X 10^6 km^2 drainage basin in Brazil, and includes nonforest vegetation such as cerrado (the dry scrub savanna of central Brazil), pantanal (Mato Grosso humid savanna) and lavrado (Roraima humid savanna). About 85% of the Legal Amazon had forest as its original vegetation. The term "deforestation" refers to loss of original forest (i.e., not including clearing of cerrado or re-clearing of secondary forests). In Pará and Maranhão (the two principal states with early areas of agricultural settlement) secondary forest areas were identified and are considered to be deforested. Deforestation does not

include disturbances such as selective logging that leave forest canopy intact. Flooding by hydroelectric dams is considered to be deforestation (although it is tabulated separately); flooded areas are counted where standing trees are dead, but not areas near reservoirs where the forest appears altered because of a rise in the water table. Small islands in the reservoirs not measurable at the scales used are counted as flooded. The forest loss to reservoirs discounts the portion of the water surface occupied by the river bed in each reservoir. To avoid double counting, previous clearing in the reservoir areas is only considered as flooded.

(Figure 1 here)

Operationally, deforestation is what appears as cleared on a LANDSAT image -- therefore omitting small openings that cannot be measured at the scales used. The minimum size of clearings included is limited by the ability to measure areas on the images, rather than by the resolution of the sensors. The smallest area measurable on the images is 1 mm^2, which corresponds to 6.25 ha in the case of 1: 250,000 scale images used from 1988 onwards, and 25 ha on the 1: 500,000 scale images used for 1978. On cannot, of course, be certain that no deforested areas larger than these minima have been omitted, especially in locations where both the original vegetation and the current landscape are complex mixtures, as in Maranhão.

Extent of Deforestation

LANDSAT Surveys of Deforestation

Estimates of deforested area in Brazilian Amazonia have varied widely. Much of this variation is the result of differences in methods or of errors in data interpretation which have since been clarified. The range of scientific doubt about these numbers is much less than many believe.

Part of the confusion surrounding deforestation numbers is the treatment of the cerrado (scrub savanna), which, because it has been much more quickly cleared than the forest, can almost double the estimates for clearing if included. Until LANDSAT images for 1988 were interpreted in 1989 (7), all previous LANDSAT estimates had included clearing in the cerrado area along with that in the forest (e.g. 2, 8-11). The 1978 data set has now been re-interpreted to separate forest from cerrado clearing and allow comparisons over time (1). In addition, re-clearing of older secondary forest had originally not been separated from primary forest clearing for the 1978 data set, but has now been separated to make it consistent with later data sets (re-clearing of secondary forests is not considered as deforestation here, since these areas are already classed as deforested). The number

of images in the mosaics for 1988 and 1989 has been increased, greatly reducing the problems of incomplete coverage. A better treatment of areas covered by clouds has improved the reliability of the estimates. Over time, errors in earlier image interpretation and in computations of the results have been uncovered, and the number of checks on data consistency has been greatly increased. Errors in the 1989 data set have been the source of several large revisions in the estimates for extent and rate of deforestation. The estimate for 1989 originally announced by the National Institute for Space Research (INPE) in June 1990 (4), was too high because hectares had been confused with square kilometers in two images from the state of Amazonas (corrected in 12). Subsequently an inconsistency in the delineation of forest and cerrado in Maranhão was corrected, and it was found that the flooding from the Tucuruí reservoir had not been included in the 1989 data set. Mainly as a result of these corrections, estimates of deforestation rate for the 1988-1989 interval decreased from 33 X 10^3 km^2/year (4) to 26 X 10^3 km^2/year (12) to 19 X 10^3 km^2/year (1). The current best estimates are given in Table 1 and Figure 2.

(Table 1 here)
(Figure 2 here)

Evaluating Forest Loss

The percentage of Brazil's Amazon forests that have been lost so far is a subject of frequent controversy, both in arriving at the correct numbers and in interpreting whether the percentage adopted represents a lot or a little. The percentages given by different sources vary tremendously, largely because of the ease with which percentages can be changed by the selection of what to include in the numerator and denominator of the calculation. In January 1989 then Brazilian president José Sarney announced that only 5% of the Legal Amazon had been cleared through 1988, and reaffirmed this figure in an interview published in the 20 February 1989 issue of Time (13). Only in the following month, in March 1989, did INPE receive the enlargements of the LANDSAT images that were later interpreted to give the same result of 5% deforestation (see 14 for a detailed analysis of this and other contemporaneous estimates). The percentage was so low mainly because the numerator did not include clearing from prior to 1960, and because the denominator used was the area of the Legal Amazon, which includes cerrado and other non-forest vegetation types that had been excluded from the deforestation value used in the numerator of the calculation. The best figure for deforestation loss through 1988 is 9.3% (based on Table 1), almost double the 5.12% calculated by INPE (7). The INPE study had been requested by Sarney specifically to discredit an estimate by the World Bank (10) that had claimed that 11% of the region was cleared (see 15 for a detailed review of this controversy and of technical problems with the World Bank

estimate). Through 1991, official announcements of deforestation percentages continued to use the area of the Legal Amazon as the denominator, although the numerators used from 1990 onwards have included older deforested areas. In May 1992 INPE distributed its 1991 deforestation results without any reference to percentages (5), although government officials continue to announce the results as percentages calculated using the area of the Legal Amazon as the denominator. This gives rise to the frequent claim that only 8.5% of the Legal Amazon has been deforested. Alberto Setzer (16) charges that "the reasons that such an error has been perpetuated are certainly neither technical nor scientific," and suggests that the invalid percentage is used so as not to produce a result in the range calculated earlier by the World Bank. The INPE team interpreting the LANDSAT images attributes the three-year delay in producing an estimate of original forest area to lack of time to digitize the forest/cerrado boundary while at the same time producing annual estimates of deforestation. Whatever the reasons, it is time to end the practice of using percentages known to be invalid rather than using the best estimate based on currently available data.

A series of deforestation percentage estimates have been made as information on forest areas has evolved. The first approximation used forest areas measured from very large scale maps published by INPE (7), resulting in an original forest area of 4.2×10^6 km^2 (14). Measurements of forest area digitized from the 1:5,000,000 vegetation map of Brazil (17) produced a value of 4.3×10^6 km^2 (18). The percentages presented here (Figure 3) are based on forest area estimates for each 1:250,000 LANDSAT image done by the INPE team that measured the clearings, making it more likely to be comparable with the criteria used in the interpretation of deforestation itself. The total forest area so derived is 4.0×10^6 km^2, resulting in a best current estimate of 10.5% for original forest cleared by 1991. The denominators used in calculating the percentages in Figure 3 are still preliminary, and will be revised when INPE's digitization of the forest/cerrado boundary is complete.

(Figure 3 here)

Much lower deforestation percentages are often presented by exploiting the common confusion of Amazonas with Amazonia. Amazonas state governor Gilberto Mestrinho frequently states that Amazonas is only 1.24% deforested (Note: the best estimate is 1.6%, including the Balbina Hydroelectric Dam in the numerator and excluding non-forest areas from the denominator). Reference to the 1.24% figure is usually immediately followed by the conclusion that "Amazonia" is still intact. Even well-educated Brazilians frequently confuse Amazonas with Amazonia, and confusion of the two is virtually universal among foreigners unfamiliar with Brazil. Amazonas is one of the least deforested

among the nine states of "Amazonia Legal" (the Legal Amazon). The 10.5% deforestation percentage for the region as a whole is almost seven times higher than the corresponding figure for Amazonas. The regional total gives little idea of deforestation's impact in specific locations: while the state of Amazonas has so far been little affected, the situation is totally different where clearing is most advanced, as in the state of Maranhão -- now 65.8% deforested (Figure 3).

Even more divergent than the values for the percentage deforestation is the interpretation of whether the results indicate that deforestation is a problem: is it an insignificant matter raised only by "alarmists" or does it threaten to rapidly devour the remainder of the forest causing an environmental and human catastrophe? While 10.5% of the forest may seem small, it should be remembered that almost all of this forest has been destroyed in the last few years. The percentage deforested increased from approximately 2.4% at the time of the launching of the Transamazon Highway in 1970 to 3.8% in 1978 to 10.5% in 1991. The deforestation that we see today is not something that has occurred gradually "since Cabral discovered Brazil [in 1500]", as described in April 1989 by then president José Sarney when announcing INPE's estimate of deforestation done for Our Nature Program (Note: Sarney's reference to the time since Europeans arrived in Brazil was even more in error, since old deforestation had been excluded from the INPE estimate; see 14). Unfortunately, deforestation today is rapid, and is quite capable of devouring the rest of the forest in a twinkling of an historical eye.

The principal danger of spreading deforestation comes from its spatial distribution. Although most of the clearing is concentrated along the southern and eastern edges of the forest, a smaller but more threatening area is spread out along highways that now penetrate much of the region. This proliferation increases the danger that deforestation can spread quickly into relatively untouched areas. Plans for future highway construction would open up much wider areas, including the vast areas now only accessible by river in the western part of the state of Amazonas. Once road access is opened up, much of the deforestation process passes outside of the control of government decision-makers (19).

The area deforested is already large: the 426×10^3 km^2 cleared through 1991 is almost the size of the US state of California. It has almost all been converted to nonsustainable cattle pasture, which degrades after about a decade of use (20-22). The cleared area has already passed the limits of Brazil's financial and physical resources (such as phosphates) for maintaining permanent agriculture, ranching or silviculture (see 23, 24). Still, most of the forest remains standing: the glass is still almost 90% full.

Rate of Deforestation

Methods for estimating rates

Deforestation rates can be calculated from the deforestation extent estimates for 1978, 1988, 1989, 1990 and 1991. The dates associated with the 1978 and 1989 data sets were determined by averaging the dates of the images used for each scene, and then averaging the scene means. The average date for the 1988 data set was determined from the time period elapsed between the 1988 and 1989 images divided by the corresponding average of the increments between the two data sets. This procedure maintains the relationship between the increment, the rate, and the time interval. The 1988 and 1989 image dates are not completely free of uncertainty because of the overlap between LANDSAT scenes: depending on cloud cover, the maps prepared from tracing over the images use one or the other of two adjacent scenes for the overlap strip (approximately 15% of the area of each LANDSAT scene).

The average rate of clearing over the period from 1978 to 1988 was 22 X 10^3 km^2/yr $\pm$ 10%. The uncertainty range of $\pm$ 10% results from 5% uncertainty from human inconsistency in measuring overlays of 1: 250,000 scale images (tested by Tardin et al., 4), together with a rough estimate of the uncertainty associated with the re-analysis of the 1978 data set.

The deforestation rates for the 1988-1989 period onwards can be determined with greater reliability than the rates for preceding periods because the sets were produced by the same sensor (the Thematic Mapper, or TM) carried on the same LANDSAT-5 satellite. Because the orbits for these years are identical, the time intervals can be determined on a scene-by-scene basis, rather than using averaged image dates for states or for the Legal Amazon as a whole.

The annual cycle of deforestation activity in different parts of the region was approximated based on meteorological data. A study of 363 clearings near Altamira, Pará, provides the frequency by month for felling activity in that location (25, p. 186). Comparison of the Altamira felling month frequency distribution with the long-term average distribution of rainfall was used to estimate the approximate felling months for other locations. The rainfall distribution for each LANDSAT scene was assigned based on the nearest meteorological station, considering the 41 stations in Brazil's Legal Amazon region and around its periphery used in Brazil's "climatological atlas" for Amazonia (26). Image dates were converted to years using a linear interpolation for the year's felling activity within this range of months.

Spatial Distribution of Clearing Activity

The deforestation rate results presented in Table 1 indicate significant shifts in the location of deforestation activity over the past decade. If one compares the average annual deforestation rate for 1978-1988 with the rate for 1990-1991, dramatic differences are apparent among the states, in both absolute and relative terms (Table 2). For Amazonia as a whole, deforestation rate (including hydroelectric flooding) decreased by 10.5 X 10^3 km^2/yr, or 48.6%. The decrease was achieved by decreases in the deforestation rates in Pará, Maranhão, Tocantins, Rondônia, Amazonas and Acre, while deforestation rates increased in Roraima and Amapá. The regional total is dominated by the states along the eastern and southern fringes of Legal Amazonia. The explosion of deforestation in the extreme north in Amapá and Roraima, although as yet insufficient to have a significant impact on regional statistics, has been maintained consistently since 1988 (Table 2). Migrants flowing from Rondônia to Roraima have largely bypassed the intervening state of Amazonas. Roraima's government has encouraged migration, and Ottomar Pinto, the current governor, promised repeatedly during his election campaign to bring 50,000 families to Roraima to place in new settlement areas, which would more than double the population of the state.

(Table 2 here)

Discrepancies with other estimates

The deforestation rates calculated above conflict sharply with rates that have been used in several recent publications on deforestation and its impacts. The World Resources Institute (WRI) Report for 1990-1991 (27, p. 102) used 80 X 10^3 km^2/yr as the annual rate for the "1980s." Norman Myers (28-30) placed the rate as of 1988 at 50 X 10^3 km^2/yr, and the Intergovernmental Panel on Climate Change (IPCC) later used this value as the basis for greenhouse emission calculations (31, p. 101). Both estimates are based on calculations of the area burning derived from the number of fires estimated with the thermal infra-red band 3 (3.5-3.9 μm) of the Advanced Very High Resolution Radiometer (AVHRR)-- the sensor carried by the U.S. National Oceanographic and Atmospheric Administration (NOAA-9) meteorological satellite. The 80 X 10^3 km^2/yr rate used by WRI was that calculated for the year 1987, which had much more deforestation and burning than other years due to a combination of dry weather and a constitutional debate on confiscating forest areas from large ranchers for redistribution in a proposed agrarian reform program.

The 1987 estimate (32, 33), as well as the value for 1988 (34), interviews concerning which provided the basis for the numbers used by Myers (28-30), suffer from severe (and possibly insoluble) methodological problems for estimating areas burned and in converting burning information into estimates of deforestation (reviewed in 14). The correction factors used to adjust for picture elements or pixels that had only part of their area on fire (0.7) and for the proportion of the burning attributed to new forest clearing (0.4) could both be high by as much as a factor of two. A correction factor for partially burning pixels is difficult to derive because of large increases in the proportion of overestimation caused by small increases in fire temperature (a highly variable parameter)--theoretical calculations show that a fire of only 900 m^2 is sufficient to trigger an entire AVHRR pixel of 1.2 X 10^6 m^2 (35), although practical experience suggests that narrow flame fronts up to two km in length can escape detection (A.W. Setzer, personal communication, 1990). The correction factor for nonforest is high because cerrado was included in the numerator but not in the denominator when deriving the factor (see 14).

Changes in Deforestation Activity

The rate of deforestation in the Legal Amazon as a whole declined significantly between 1987 and 1991. The annual rate of 11.1 X 10^3 km^2 in 1991 was only half the 22.0 X 10^3 km^2/yr average rate between 1978 and 1988 (Table 1). It should also never be forgotten that the lower deforestation rate of 11.1 X 10^3 km^2/year is still a huge area -- half the size of the US state of Massachusetts -- destroyed each year, virtually all for unsustainable uses such as cattle pasture and with very little benefit for the people of the region. An annual rate of 11.1 X 10^3 km^2, or 1.11 X 10^6 ha, represents an average of over 3000 ha per day, or over 2 ha per minute.

The decline in deforestation rate over the 1987-1991 was greater than the above figures imply. The peak of deforestation occurred in 1987, when the entire Amazon was blanketed in smoke; unfortunately, no usable deforestation estimate exists for 1987. No complete coverage has yet been interpreted for the years between 1978 and 1988 (although interpretation is in progress at INPE for a mosaic of 1986 images and for 1984 and 1985 at selected locations). Existing studies of partial mosaics for various years between 1978 and 1988 (some of which include cerrado) suggest that the rate increased through 1987 (see 9).

The decline in deforestation rates from 1987 through 1991 does not represent a trend that can be extrapolated into the future until the deforestation problem simply disappears, as some officials have claimed. The lower rates are mainly explained by Brazil's deepening economic recession over this period. Ranchers simply do not have money to invest in expanding their clearings

as quickly as they have in the past. In addition, the government has lacked funds to continue building highways and establishing settlement projects. Probably very little of the decline can be attributed to Brazil's repression of deforestation through inspection from helicopters, confiscating chainsaws and fining landowners caught burning without the required permission from the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). Despite bitter complaints, most people continued to clear anyway. Changes in policies on granting fiscal incentives also do not explain the decline. The decree suspending the granting of incentives (Decree No. 151) was issued on 25 June 1991--after almost all of the observed decline in deforestation rate had already occurred (Figure 2). Even for the last year (1991), the effect would be minimal, as the average date for the LANDSAT images for the 1991 data set was August of that year.

Not only the past but also the potential future effect of the decree on incentives (Decree No. 153 of 25 June 1991) is much less than many believe. The decree is a modification of a previous decree (Decree No. 101 of 17 April 1991, which "regulamentates" Law No. 8167 of 16 January 1991), and only covers those incentives that were included in the previous decree (i.e. only new incentives). The clauses of the 25 June 1991 decree also mention explicitly measures that should be taken by the Regional Development Agencies (i.e. the Superintendency for Development of the Amazon - SUDAM) "previous to the approval of new projects" (Article 15, Paragraph III, Incision 1). The small number of new ranching projects approved for incentives each year is much less important than the hundreds of projects already approved. Also, even without incentives deforestation continues to be profitable for land speculation purposes (e.g. 36). This is shown by a LANDSAT survey of the Belém-Brasília Highway area (the most heavily subsidized part of Amazonia) done at the height of the incentives program in the late 1970's: 45% of the deforestation in the area was in properties (virtually all large ranches) without any incentives (11, p. 19).

The overriding importance of the economic recession means that deforestation rates can be expected to increase again once Brazil's economy recovers, unless the government takes steps now to remove the underlying motives for deforestation. Steps needed include: applying heavy taxes to take the profit out of land speculation, changing land titling procedures to cease recognizing deforestation for cattle pasture as an "improvement" (benfeitoria), removing the remaining subsidies, reinforcing the procedures for the Environmental Impact Report (RIMA), carrying out agrarian reform both in Amazonia and in the source areas of migrants, and offering alternative employment both in rural and in urban areas. A more detailed description of needed steps to slow deforestation is presented elsewhere (37).

LARGE VERSUS SMALL LAND-HOLDINGS

The notion that deforestation is the result of poor people clearing to feed themselves is promoted by politicians in Brazilian Amazonia to justify their claims that anyone suggesting that deforestation is harmful or should be reduced is against the people. Central government officials have also begun to blame the poor for clearing, using the (erroneous) argument that clearing by large ranchers has been controlled by suspending incentives, so that the remaining clearing is the work of small farmers. The evidence to be presented here shows that none of these claims is true. Relatively little deforestation in Brazil is due to subsistence agriculture; established cattle ranching projects continue to receive government subsidies, and ranches (many of which never had incentives) continue to account for most deforestation. The social costs of greatly reducing the rate would therefore be much less than is implied by those who blame poverty for deforestation. The accusation of being "against the people" is particularly galling to environmentalists and scientists working on the problem of deforestation, many of whom are profoundly concerned with the poverty that has long prevailed in the Amazonian interior.

The question of who is to blame for tropical deforestation has profound implications for the priorities of programs intended to reduce forest loss. A common generalization is that the principal culprit is the "shifted cultivator" (29), meaning small pioneer farmers who migrate to tropical forest areas. A "Deforestation Reduction Initiative" aimed at channeling international resources into programs that would help to reduce greenhouse gas emissions from tropical deforestation worldwide starts from the assertion that "people do not cut tropical forests because they like to; they clear land out of sheer necessity to grow more food" (38, p. 377). Such generalizations fail to recognize that Brazil is different from many other locations. When Brazil's differences are recognized at all, they tend to be relegated to caveats attached to global generalizations. However, Brazil is too big to be relegated to a caveat.

Attributing tropical deforestation to poor shifting cultivators is particularly inappropriate for Brazil, where most clearing is done on large properties for cattle ranching (often motivated by land speculation). Measures aimed at containing deforestation by, for example, promoting agroforestry among small farmers can never achieve this goal, although some of the same tools (such as agroforestry) have important reasons for being supported independent of efforts to combat deforestation (24).

The distribution of 1991 clearing among the region's nine states (Figure 4) indicates that most of the clearing is in states that are dominated by ranchers: the state of Mato Grosso

alone accounts for 26% of the 11.1 X 10^3 km^2 total. Mato Grosso has the highest percentage of its privately held land in ranches of 1000 ha or more: 84% at the time of the 1985 agricultural census (Table 3). A moment's reflection on the human significance of having 84% of the land in large ranches (and only 3% in small farms) should give anyone pause. By contrast, Rondônia -- a state that has become famous for its deforestation by small farmers -- had only 10% of the 1991 deforestation total, and Acre had 3%.

(Figure 4 here)
(Table 3 here)

No direct measurement exists of how much of the clearing is taking place on large ranches as opposed to small holdings, although it is technically feasible to measure clearing from LANDSAT images on a property-by-property basis. An indirect estimate is much better than the alternative of assuming that deforestation is divided evenly among the region's approximately 8 X 10^6 rural residents. One can obtain an estimate of the relative importance of the different property classes from the distribution of deforestation activity among the nine states of the Legal Amazon. Multiple regressions of deforestation rate and the numbers of properties identified in the 1985 agricultural census in each class (<100 ha, 100-1000 ha, and >1000 ha) can be used to derive coefficients indicating the number of hectares cleared per year per property (Table 4). The number of properties in each class explains 74% of the variance in state-level deforestation rates ($p < 0.05$, N=9) both for 1990 and for 1991. In both years the small farmers accounted for about 30% of the deforestation activity, with 70% being done by ranchers.

(Table 4 here)

While small farmers account for only 30% of the deforestation activity, the intensity of deforestation within the area they occupy is greater than for the medium and large ranchers that hold 89% of the Legal Amazon's private land. Deforestation intensity, or the impact per km^2 of private land, declines with increasing property size (Table 5). This means that deforestation would increase if forest areas now held by large ranches were redistributed into small holdings. This indicates the importance of using already cleared areas for agrarian reform, rather than following the politically easier path of distributing areas still in forest. Large as the area already cleared is, it has limits that fall far short of the potential demand for land to be settled. Indeed, even the Legal Amazon as a whole falls short of this demand (39). Recognizing the existence of carrying capacity limits, and then maintaining population levels within these, is fundamental to any long-term plan for sustainable use of Amazonia (24, 40).

(Table 5 here)

DEFORESTATION VERSUS SUSTAINABLE USE

Amazonia's rural population is now supported in ways that can only be temporary (22, 25, 41-45). Agriculture and cattle ranching activities are unsustainable as practiced, and unlikely to be converted into sustainable systems over sufficiently wide areas (46). Timber extraction is predatory, and unlikely to take place as sustainable management under the current economic system (47). Harvest of non-timber extractive products is important as a potentially sustainable use of forest in some areas, but has little potential to absorb large human populations (48).

Radically new means of support are needed for Amazonia's population, both in rural and in urban areas. In rural areas, the existing potential must first be used for agriculture in already deforested areas and extractive use of designated areas of standing forests. However, the key to making use of standing forest economically attractive is likely to lie not in fine-tuning the economic system surrounding forest commodities, but rather in developing ways to turn the supply of environmental services into a part of the solution to supporting the local population. Appropriate institutional mechanisms are now totally lacking. The first step is research on valuation of environmental services. These include biodiversity maintenance, carbon storage and water recycling. Institutional mechanisms for negotiating international agreements on these values come next. Separate institutions are then needed to collect funds on the basis of the services agreed upon, and to apply these to programs that will result in achieving the two objectives: supporting the population and maintaining forest with its services intact.

Supporting a dense rural population is not a viable goal for the region's development. Use of standing forest represents the best path to providing a basis for supporting the modest number of people that can be maintained sustainably. Such uses do not offer a solution to supporting the many migrants who have come to the region and are now engaged in agriculture, ranching, logging and goldmining activities. Support for many of these people will sooner or later have to be found outside of rural Amazonia -- especially in the urban sector.

By clearing the forest, the opportunity to use it sustainably is being thrown away. Halting the current pattern of deforestation for nonsustainable cattle pasture should be the first priority in any strategy for sustainable development in the region. The dominant role of medium and large ranchers in Brazil's Amazonian deforestation, together with the meager social benefit they represent, indicates that the first priority should be measures to remove the profit from forest clearing by these most damaging actors.

References and Notes

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6. The Legal Amazon was created in 1953, encompassing all or part of the present states of Amapá, Amazonas, Acre, Rondônia, Roraima and Pará, plus Maranhão west of 44^{o} W Longitude, Goiás (now Tocantins and Goiás) north of 13^{o} S Latitude, and Mato Grosso north of 16^{o} S. Latitude. In 1977 the former state of Mato Grosso was divided into the present states of Mato Grosso and Mato Grosso do Sul, and the southern limit of the Legal Amazon was extended to the new interstate boundary. Tocantins is a state created by Brazil's October 1988 constitution from the northern tip of the former state of Goiás; a small portion of its territory (7411 km^2 of 277,322 km^2) lies south of 13^{o} S Latitude, while the present state of Goiás has a small area--estimated at 2875 km^2 from the 1:5,000,000 map--north of this former boundary of the Legal Amazon. The data sets here have been reinterpreted to conform to the present boundaries of the Legal Amazon.

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Table 1 notes:

(a) Legal Amazon average image date of 14 Jan. 1978 used for all political units.

(b) Average image dates by state used in 1978-1988 rate calculations: Acre 23 Mar. 1988; Amapá 10 Sept. 1987; Amazonas 23 Mar. 1988; Maranhão 6 Mar. 1988; Mato Grosso 3 Apr. 1988; Pará 10 May 1988; Rondônia 11 Aug. 1988; Roraima 30 Apr. 1988; Tocantins 11 Aug. 1988.

(c) Based on Tardin and da Cunha (3), as modified by Fearnside et al. (1).

(d) Uses intervals of ten years for all political units except Rondônia, Roraima and Tocantins, for which the interval is 11 years. Intervals are rounded to the nearest year based on the state average image date for 1988 and the Legal Amazon average image date for 1978.

(e) Time interval calculated by individual LANDSAT scene.

(f) Maranhão values include 57.8 X 10^3 km^2 of "old" (approximately pre-1960) deforestation now mostly under secondary forest.

(g) Pará values include 39.8 X 10^3 km^2 of "old" (approximately pre-1960) deforestation now mostly under secondary forest.

FIGURE LEGENDS

Figure 1 -- Brazil's Legal Amazon region

Figure 2 -- Extent and rate of deforestation in the Brazilian Legal Amazon

Figure 3 -- Percentage of original forest lost by 1991

Figure 4 -- Distribution of 1991 deforestation activity by state

TABLE 1: EXTENT AND RATE OF DEFORESTATION IN THE BRAZILIAN LEGAL AMAZON

Political unit	Deforested area (km^2 X 10^3)					Deforestation rate (km^2 X 10^3/year)			
	1978 (a)	1988 (b)	1989 (c)	1990	1991	1978-1988 (d)	1988-1989 (e)	1989-1990	1990-1991
	DEFORESTATION EXCLUSIVE OF HYDROELECTRIC DAMS								
Acre	2.5	8.9	9.8	10.3	10.7	0.6	0.6	0.6	0.4
Amapa	0.2	0.8	1.0	1.3	1.7	0.1	0.2	0.3	0.4
Amazonas	1.7	17.3	19.3	19.8	20.8	1.6	1.3	0.5	1.0
Maranhao	(f) 63.9	(f) 90.8	(f) 92.3	(f) 93.4	(f) 94.1	2.7	1.4	1.1	0.7
Mato Grosso	20.0	71.5	79.6	83.6	86.5	5.1	6.0	4.0	2.8
Para	(g) 56.3	(g) 129.5	(g) 137.3	(g) 142.2	(g) 146.0	7.3	5.8	4.9	3.8
Rondonia	4.2	29.6	31.4	33.1	34.2	2.3	1.4	1.7	1.1
Roraima	0.1	2.7	3.6	3.8	4.2	0.2	0.7	0.2	0.4
Tocantins	3.2	21.6	22.3	22.9	23.4	1.7	0.7	0.6	0.4
Legal Amazon	152.1	372.8	396.6	410.4	421.6	21.6	18.1	13.8	11.1

FOREST FLOODED BY HYDROELECTRIC DAMS

0.1	3.9	4.8	4.8	4.8	0.4	1.0	0.0	0.0

DEFORESTATION FROM ALL SOURCES

152.2	376.7	401.4	415.2	426.4	22.0	19.0	13.8	11.1

TABLE 2: ABSOLUTE AND RELATIVE CHANGES IN DEFORESTATION RATES BY STATE

Political unit	Change in deforestation rate for 1988-1989 relative to 1978-1988		Change in deforestation rate for 1989-1990 relative to 1988-1989		Change in deforestation rate for 1990-1991 relative to 1989-1990		Change in deforestation rate for 1990-1991 relative to 1978-1988		Deforestation rate for calculation
	(km^2X10^3/year)	(% change)	(km^2X10^3/year)	(% change)	(km^2X10^3/year)	(% change)	(km^2X10^3/year)	(% change)	
Acre	-0.1	-13.9	0.0	0.9	-0.2	-31.9	-0.3	-40.8	
Amapa	0.1	189.8	0.1	48.0	0.1	56.5	0.3	571.0	
Amazonas	-0.3	-17.5	-0.8	-58.6	0.4	83.9	-0.6	-37.2	
Maranhao	-1.3	-46.8	-0.3	-22.3	-0.4	-39.7	-2.0	-75.1	
Mato Grosso	0.8	16.0	-1.9	-32.6	-1.2	-29.5	-2.3	-44.8	
Para	-1.5	-21.1	-0.9	-15.2	-1.1	-22.9	-3.5	-48.3	
Rondonia	-0.9	-37.4	0.2	16.1	-0.6	-33.8	-1.2	-51.9	
Roraima	0.4	183.7	-0.5	-76.1	0.3	160.9	0.2	76.9	
Tocantins	-0.9	-55.6	-0.2	-21.0	-0.1	-25.2	-1.2	-73.8	
Legal Amazon	-3.6	-16.6	-4.2	-23.5	-2.7	-19.5	-10.5	-48.6	

TABLE 3: LAND TENURE DISTRIBUTION THE BRAZILIAN LEGAL AMAZON IN 1985(a)

State	Number of establishments				Area of establishments (Hectares)			total area	Area of establishments (10^3 hectares
	<100 ha	100-1000 ha	>1000 ha	total no. prop.	<100 ha	100-1000 ha	>1000ha		<100 ha
Acre	21,026	13,966	323	35315	983006	2526788	2416649	5926443	
Amapa	3,027	1,683	122	4832	69162	288324	853044	1210530	
Amazonas	107,454	8,798	557	116809	1687997	1817661	2461893	5967551	1,6
Maranhao(b)	252,171	11,448	1,155	264773	1514739.5	5945200	3168221.5	10628161	1,5
Mato Grosso	55,403	17,331	5,575	78309	1217114	5046642	31698678	37962434	1,2
Para	215,020	36,505	2,418	253943	4870488	6268784	12392775	23532047	4,8
Rondonia	65,469	15,581	474	81524	2121960	2168490	1800194	6090644	2,1
Roraima	2,913	2,936	574	6423	146235	489529	1521362	2157126	
Tocantins (Goias)(b)	52,659	32,270	4,684	89612.5	1807423.5	9867058	24237861	35912342.5	1,8
LEGAL AMAZON	775,142	140,517	15,882	931540.5	14418125	34418476	80550677.5	129387278.5	14,4

(a) Data from 1985 agricultural census (49, p. 297).
(b) For Maranhao and Tocantins (Goias), half of the properties are assumed to be in the Legal Amazon.
The state of Tocantins was created from the northern half of Goias in 1988, roughly the portion in the Legal Amazon.

TABLE 4: DEFORESTATION ACTIVITY BY PROPERTY SIZE

Year	Deforestation(ha property^{-1} year^{-1})			Regression statistics	
	Small farmers (<100 ha)	Mid-sized ranches (100-1000 ha)	Large ranches (>1000 ha)	p	r^2
1990	0.31*	3.66	28.92	<0.05	0.74
1991	0.24*	3.18	18.10	<0.05	0.74

* The small farmer per-property estimate shown here assumes that the approximately 670 000 families unaccounted for in the 1985 agricultural census are "small farmers." Since the unaccounted-for families are allocated among the states in proportion to the censused small farms, this does not alter the other coefficients, the regression statistics, or the distribution of deforestation as a percent of the yearly total. Without this adjustment, the clearing by small farmers would be 0.58 ha · property^{-1} in 1990 and 0.45 ha · property^{-1} in 1991.

TABLE 5: RATE, INTENSITY AND DISTRIBUTION OF DEFORESTATION BY PROPERTY SIZE

Property Size	Private land		Deforestation rate (10^3 km^2/year)		Deforestation distribution (% of annual total)		Deforestation intensity (ha/year/km^2 private land)	
	Area (10^6 ha)	Distri-bution (%)	1990	1991	1990	1991	1990	1991
Small (<100 ha)	14.4	11.1	4.21	3.39	30.5	30.5	3.05 (*)	2.33 (*)
Medium (100-1000 ha)	34.4	26.6	5.06	4.65	36.6	41.8	1.49	1.29
Large (>1000 ha)	80.6	62.3	4.55	3.09	32.9	27.8	0.57	0.36
Total	129.4	100.0	13.8	11.1	100.0	100.0	1.09	0.83

(*) Intensity for small properties may be substantially lower due to unregistered properties in the IBGE Agricultural Census.