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THE RATE AND EXTENT OF DEFORESTATION IN BRAZILIAN AMAZONIA

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AVAILABLE ESTIMATES

Types of Data Sources

Controversy surrounds the existing estimates of the extent and rate of deforestation in Brazilian Amazonia. Other estimates have produced values substantially higher or lower than the ones derived in the present paper, which estimates that through 1988, 8.2% of the originally forested portion of the Brazilian Amazon had been cleared (including old clearings), with new clearing in the forest (virgin + old secondary forest) area expanding at 20×10^3 km^2/year.

Data on deforestation are now available from a variety of satellites. Some of the conflicting values presented for the extent and rate deforestation are due to differences in the sensors and interpretation techniques used. The LANDSAT satellites of the U.S. National Aeronautics and Space Agency (NASA) are the source of much valuable information on deforestation. This satellite is designed for monitoring land resources, and is well suited to measuring deforested areas. Its main limitations are the high cost of images for a large area such as Amazonia, and the difficulty of obtaining cloud-free images because of relatively infrequent coverage (once every nine days with two satellites in operation). From the time the first LANDSAT satellite was launched in 1972 until 1982, all data were collected by the Multispectral Scanner (MSS) with a resolution of 80 m (that is, with the image made up of picture elements or pixels each corresponding to an area measuring 80 m X 80 m). Since 1982, data from the Thematic Mapper (TM), with a resolution of 30 m, are also available. Data may be analyzed either by computer-aided interpretation of digital tapes, or by manual interpretation of paper images. Digital interpretation has the advantage of eliminating inconsistencies among cartographers in their judgement as to what is to be counted as deforestation. Smaller clearings can also be included using digital methods. On the other hand, manual interpretation of paper images allows greater opportunity for the application of common sense in distinguishing, for example, between cattle pastures and spectrally-similar patches of "natural" grassland: pasture is usually in rectangular blocks whereas "natural" grassland (which may owe its presence in part to burning by indigenous peoples) has irregular curved edges.

In the case of photographic interpretation, the scale of images used can greatly affect the reliability of the resulting estimates. Paper images can be obtained at scales ranging from 1: 100,000 to 1: 1,000,000; most deforestation estimates use either 1: 250,000 or 1: 500,000 scale.

The Advanced Very High Resolution Radiometer (AVHRR),

carried by the U.S. National Oceanographic and Space Administration (NOAA) weather satellites, provides a means of monitoring deforestation that is cheaper but coarser than LANDSAT. Images are obtained daily, making cloud-free coverage much more likely than for LANDSAT. Data can be obtained at a resolution of 1.1 km, but most data are recorded at 3.4 km resolution. Deforested areas can be measured using a normalized difference relationship between the first two of the five spectral channels recorded by the sensor (0.55-0.68 um and 0.73-1.1 um) (Tucker et al., 1984). Pixels containing fires can be located and counted using the third and fourth channels (3.5-3.9 um and 10.5-11.5 um) (Setzer et al., 1988). The area of the fires, which may be much smaller than the 120 ha pixel size of 1.1 km resolution AVHRR data, cannot be reliably estimated.

The French satellite SPOT, with a resolution of 10 m, has since 1986 produced images sufficiently detailed to detect even the smallest clearings. However, the high cost of the images make them impractical for monitoring large areas. Coverage of the Brazilian Amazon would cost approximately US$ 3 million. SPOT data are important for calibrating other remote sensing tools, but no data are available covering areas sufficiently large for direct use in estimating deforestation in the Brazilian Amazon.

Problems in interpreting the available data include the fact that deforestation results from different studies often refer to overlapping but different geographical areas. Many studies only cover a portion of a political unit such as a state, making it hard to use the results in conjunction with available state-level data. Interpreting study results by vegetation type, such as forest and cerrado (the central Brazilian scrub savannah), is often hampered by inconsistencies among the definitions of the vegetation types by different studies, and by frequent lack of explanation of the criteria used. Most data in Brazil refer to the "Legal Amazon," a 5 X 10^6 km^2 administrative region to which special tax incentives and development programs apply. The Legal Amazon covers all or part of nine states; depending on the definitions of forest, approximately 70-80% of the region is forest, while the remainder is savannah such as the cerrado (Figure 1). Because data have only been available for the areas of clearing, but not for the original area of the vegetation under consideration, percentages have invariably been expressed using the areas of political units as denominators. This practice understates the relative extent of clearing, since humid savannahs are included in the denominators but not in the numerators. Many calculations also include water surfaces in the denominators. The distortion from using the areas of political units is unfortunate, but at least has allowed more-or-less consistent values to be compared between years. Recently, however, a much larger bias of this type has been introduced by an INPE study of 1988 images that excluded the cerrado from the

numerator while continuing to divide by the area of political units (Brazil, INPE, 1989a,b).

An examination of some of the problems affecting different satellites and interpretation techniques will make clear why widely different conclusions are reached. Despite the difficulties, it is essential that the most reliable information be identified for each location.

AVHRR Burning Estimates

One study that has received widespread public attention estimated areas burning using infra-red bands of AVHRR. The study, conducted at Brazil's Institute for Space Research (INPE) meteorology department, concluded that 204,000 km^2 burned in 1987 in the Brazilian Legal Amazon, of which 80,000 km^2 represented new deforestation in the region's forested portion (Setzer et al., 1988). Most of the difference between 204,000 km^2 (20 million ha) and 80,000 km^2 (8 million ha) represents burning of cerrado, cattle pasture or other land uses. The value for the total area burned is also too high, in part because 427,331 km^2 in the states of Goiás and Maranhão outside the Legal Amazon were included (see Figure 1).

The 80,000 km^2 1987 value for clearing in the forest area is too high for two reasons. One is lack of an objective method for estimating the percentage of burning that represents new deforestation. To estimate this fraction, the value from AVHRR for area burned is multiplied by a correction factor--the quotient of a "reference value" (the area of original forest known by independent means to really have been cleared in the region during a given year divided by the value measured by AVHRR as burning in the same year). The 40% correction factor used by Setzer and co-workers (1988) was derived by Pereira (1987: 142), who compared an AVHRR infra-red estimate of area burning with a reference value for deforestation in the same year, and estimated that 67,000 km^2 was burning in the portion of the Legal Amazon covered by the 1985 AVHRR image he used (south of the equator). Pereira's value referred to the forest areas of the entire Legal Amazon, an area somewhat larger than that covered by the AVHRR image (deforested area north of the equator is small, however). The "reference value" (27,000 km^2) was taken from a newspaper report of an interview with Carlos Marx Ribeiro Carneiro (Marcos da Costa Pereira, personal communication, 1987). In addition to the apparent lack of a methodological basis for the reference value, it is probable that the number used was intended by its source to apply to both cerrado and forest clearing, rather than just forest as assumed by Pereira (1987). Carlos Marx Ribeiro Carneiro, who had coordinated IBDF's LANDSAT survey of 1980 deforestation, used this larger administrative unit in his earlier estimate (Brazil, IBDF, 1983a). Forest clearing would therefore represent only a fraction (about half) of the 27,000

km^2 total, and the correction factor and corresponding value for deforestation would be proportionately smaller. No objective determination yet exists of the correction factor appropriate for calculating forest clearing from information on burned areas in the Legal Amazon.

The second reason for overestimation of burned areas is saturation of the sensor when even a relatively small fire is present within one of the 120 ha pixels. Theoretical calculations indicate that a fire of only 30 m^2 is sufficient to make the whole of the 1,200,000 m^2 pixel in which it is located appear as though it were on fire (Robinson, nd). The constant correction factor of 0.7 used to adjust for partially burning pixels is insufficient. The correction factor was derived by Pereira (1987: 142) by comparison of 1985 AVHRR and LANDSAT-TM results for an area in northern Mato Grosso. However, the sharp dependence of sensor saturation on fire temperature makes deriving a constant correction factor difficult. The relationship is nonlinear: a tiny increase in fire temperature results in a tremendous increase in the percentage of overestimation from partially burning pixels. Fire temperature varies greatly depending on weather and fuel load conditions.

Even if it were possible to obtain an accurate measurement of the area of the flame front, translating this into area burned would be difficult. The NOAA satellites pass over Amazonia daily at about 14:00 h, and the measurements capture only what is burning at the instant the image is taken. Since fires start at one side of a felled area and move across it over the course of about half a day, the area burned is larger (by a highly variable amount) than that which is burning at any given instant. Estimating the area of fires is also hampered to a variable degree by thick clouds of smoke that blanket the region at the height of the burning season.

Overestimation due to saturation of the sensor is indicated by a discrepancy for Rondônia between the AVHRR mid infra-red measurement of burning and another AVHRR measurement in the same state and year using reflected light from deforested areas, both using digital analysis. The area registered as burning in Rondônia (18.7% of the state: Setzer et al., 1988: 28)--equivalent to approximately 40% deforestation since each hectare is burned once every 2-3 years--is much higher than the cumulative deforested area through the same year (15.1%) measured by Jean-Paul Malingreau (personal communication, 1988; see Fearnside, 1990a). Some of this discrepancy may be explained by fires in neighboring portions of Bolivia having been inadvertently included in the Rondônia estimate (A.W. Setzer, personal communication, 1989), but insufficient correction for saturated pixels is the likely cause of much of the overestimation by roughly a factor of two. Possible overestimation in the AVHRR deforestation result would only

further increase the discrepancy with the burning results from AVHRR infra-red measurements: a corrected AVHRR clearing estimate for 1987 indicates only 32,282 km^2 (13.3% of the state) deforested by that year (Appendix: Rondônia; Table 3, Note b). The more detailed and accurate LANDSAT study for the same year reports 22,913 km^2 (9.4%) cleared (Brazil, IBDF, 1989).

The INPE researchers have recently made an AVHRR infra-red estimate of burning in 1988 indicating 121,000 km^2 total in the Legal Amazon, 48,000 km^2 (40%) of which is attributed to new deforestation in the forest area (Setzer et al., in preparation; data reproduced in Tuffani, 1989). The 1988 estimate does not include areas outside the Brazilian Legal Amazon, but uses the same subjective correction factors as the 1987 estimate to adjust for burning that is not new forest clearing (40%) and for partially burning pixels (70%). The method is therefore likely to produce unreliable area values for the same reasons that affected the 1987 burning estimate. This limitation does not affect other uses of the same images, as for estimating the number of fires and for pinpointing the location of burning (including identifying violators of Brazil's environmental laws).

Norman Myers (1989: 18) has put forward a figure of 50,000 km^2/year for the current rate of forest loss in Brazilian Amazonia (including both primary and secondary forest clearing), based on the INPE Meteorology Department's thermal infra-red AVHRR estimate of 48,000 km^2 for primary forest clearing in 1988. The methodological problems described above for thermal infra-red AVHRR measurement of burned areas invalidate principal basis for this figure. As of now there is no reliable way to measure directly the areas burning using an image from a single year (as was attempted in the thermal AVHRR studies): to estimate deforestation one still must have images from two years in the same place, and calculate by difference the increase in cleared area.(1)

The World Bank Estimate

The International Bank for Reconstruction and Development (World Bank) published a report estimating that 598,922 km^2 (12.0%) of the Legal Amazon(2) had been cleared by 1988 (Mahar, 1989; see Table 1, Column E). The estimate was derived from data presented in Fearnside (1986), where LANDSAT surveys of clearing through 1980 are summarized (Brazil, IBDF, 1983a; Tardin et al., 1980). Exponential projections within each state were made by the World Bank, with the apparent exception of the value for the state of Pará. Data from more recent satellite measurements have shown that deforestation has not proceeded so quickly as it would have had the trends until 1980 continued unaltered. Over half the difference between the World Bank estimate and the linear projection estimate from the most recent data in each state is accounted for by the state of Amazonas (Fearnside, 1990a).

Amazonas, by far the largest state in Amazonia, weighs heavily in the regional total. The 6.8% indicated as deforested by 1988 (Mahar, 1989) is much higher than what is apparent on INPE's mosaic of 1986 images (Brazil, INPE, 1988). The 0.8% measured by INPE (Brazil, INPE, 1989a,b) appears to be the most reasonable value for the state of Amazonas.

The INPE/Our Nature Program Estimate

On 6 April 1989, the day of President José Sarney's announcement of the Nossa Natureza ("Our Nature") package of environmental programs, Brazil's Institute for Space Research (INPE) Remote Sensing Department released a new estimate of deforestation (differing from the INPE Meteorology Department estimate discussed previously) through 1988 (Brazil, INPE, 1989a). The Remote Sensing Department study, known as the INPE/Our Nature Program study, concluded that only 5.12% of Brazil's Legal Amazon had been deforested--substantially lower than the 8.0% indicated by linear projection from the most recent satellite data available in each state (Fearnside, 1990a). The INPE study used LANDSAT-TM images at a scale of 1: 1,000,000 to locate the most heavily deforested areas, and used 101 images at 1: 250,000 to measure deforestation in these locations (numbers from Roberto Pereira da Cunha, personal communication, 20 April 1989). The 133 images at 1: 1,000,000 not analyzed at 1: 250,000 had no deforestation apparent and were considered to be completely intact--measurements were not made on 1: 1,000,000 images (R.P. da Cunha, personal communication, 20 April 1989). No list of images was included in the initial report of the study (Brazil, INPE, 1989a,b), but a list included in a December 1989 report (Tardin and da Cunha, 1989) indicates that images were not analyzed from several areas known to have deforestation activity, especially in northern Mato Grosso and southern Pará (Figure 2).

As also occurred in previous studies, Amazonia's notorious cloud cover forced the INPE/Our Nature Program study to use a substantial number of images from years prior to the nominal year of the estimate. Of the 101 images interpreted at the 1: 250,000 scale, 73 were from 1988, 19 from 1987 (4 of which were in cerrado areas), 4 from 1986, 4 from 1985 and 1 from 1984 (Tardin and da Cunha, 1989: 11). The 73 images from 1988 listed in INPE's December 1989 report (Tardin and da Cunha, 1989) are at variance with an official note that INPE had published on 11 May 1989 stating that 88 images from 1988 had been used (Brazil, INPE, 1989c: 2). The earlier number had been released in conjunction with the hearings of a Brazilian parliamentary commission of investigation (CPI) on Amazonian deforestation (Passarinho, 1989); the head of the commission has reportedly stated that the lower number contradicts the researchers' sworn testimony at the hearings (Tuffani, 1990). This raises some doubt as to which number is correct; it will be assumed here that the lower number (73 images) given in the published list is the

correct one. The difference of 15 LANDSAT images represents 513,000 km^2--an area almost as large as France. The locations of several of the older images used coincide with known areas of intense deforestation, especially in Mato Grosso and Pará (see Figure 2).

The original 6 April 1989 report of the INPE/Our Nature Program study (Brazil, INPE, 1989a) was amended in a second edition released on 2 May 1989 (Brazil, INPE, 1989b). The 1988 measurements were originally presented as representing alteration of the "vegetation cover" (Brazil, INPE, 1989a: 37), which was amended to "forest cover" in the second edition (Brazil, INPE, 1989b: 28). Because a significant part of the Legal Amazon is cerrado or other nonforest vegetation, the restriction of the measured alteration to forested area makes the 5.12% of the Legal Amazon deforestation figure meaningless, since the numerator and denominator refer to different areas. It also makes plotting the absolute deforestation figures misleading when presented with data from previous LANDSAT studies, all of which represent alteration of both forest and cerrado rather than only forest. Obtaining a valid time series for the forested portion of the Legal Amazon should be an important priority, but this will require re-analysis of the images used in previous studies.

The revelation that the INPE/Our Nature Program values for alteration of "vegetation cover" were really referring to "forest cover" makes it indispensible to have information on the areas of forest and cerrado originally present in each state. Otherwise the deforested area values cannot be interpreted in terms of percentages. Valid comparisons are also not possible with the data from previous studies for establishing trends (although gross inconsistencies, such as decreasing deforested area, can be spotted). Unfortunately, the original areas of forest and cerrado are not included in the INPE reports. The distinction between forest and cerrado is not so simple as it might seem: no maps exist (at scales more detailed than a gross sketch) that classify the region into "forest" or "cerrado." Rather, the continuous gradations between vegetation types is broken into many finer categories--and assignment of intermediate categories to the "forest" or "cerrado" groups is somewhat arbitrary. The inconsistencies in such classifications among past studies have been one of the impediments to obtaining usable estimates of clearing in the forest area, rather than for the whole Legal Amazon.

The INPE/Our Nature Program estimate delineated forest from savannah by tracing with an erasable crayon onto the original 1: 250,000 scale LANDSAT-TM images, using 1: 1,000,000 scale vegetation maps from the side-looking airborne radar (SLAR) surveys done by the RADAM project (Brazil, Projeto RADAMBRASIL, 1973-1983). The line was drawn freehand, using as a reference the latitude and longitude coordinates printed on the images.

When the LANDSAT images were subsequently needed for display in a public exhibition, the line was erased, thus making an exact recuperation of the criteria used impossible (Carlos Alfonso Nobre, personal communication, 29 August 1989). The INPE report contains a small map (scale approximately 1: 15,000,000) presenting what is described as the limit used between forest and savannah (Brazil, INPE, 1989b: 5). The map was actually drawn from information in maps made by the Brazilian Institute for Geography and Statistics (IBGE) rather than the RADAM maps used in the study, but the team leader states that it approximately represents the forest and savannah areas that were used. In the absence of another alternative then, the map published in the report must be taken as the baseline for the original areas of forest and savannah (Figure 1). Some divergences from reality are apparent, such as the shape and location of the Humaitá savannahs in the southern part of the state of Amazonas. The forest and savannah areas represented on the map were measured gravimetrically to a precision of 645 km^2. The uncertainty associated with the map itself is not known but probably large. Table 2 presents the areas obtained for forest and savannah in each state, standardized for the area of the state that was used in the source for the deforestation estimates presented in the same table. Relative to other classifications, the criterion used in the INPE/Our Nature Program study appears to be broad in defining forest and restrictive in defining savannah. Of the Legal Amazon, 18% is classified as savannah (including both cerrado and humid savannah) and 82% as forest according to the INPE map (Figure 1). However, some doubt is cast on this by statements from INPE personnel to the effect that the criterion minimized the area classified as forest by assigning to the savannah category all vegetation not specifically containing the word "forest" in its RADAM mapping unit definition (i.e., the "transition zone"), and by assigning to savannah the long intrusions of riparian forest along rivers (Carlos Alfonso Nobre, personal communication, 19 August 1989).

The percentage values given in the INPE/Our Nature Program report are misleading because of the treatment of savannah. However, this is not the only problem in interpreting the results. Problems and doubts differ with each of the Legal Amazon's nine states (see Appendix: Data from Amazonian States). It is important to evaluate each of these, in order to make use of as much information from the INPE/Our Nature Program study as possible.

A BEST ESTIMATE FOR DEFORESTATION

The areas and percentages deforested by 1988 indicated by various studies are presented in Table 1. The trend in each state since previous LANDSAT measurements is plotted in Figure 3. If one uses clearing data from the INPE LANDSAT study with corrections for area of states and for clearing in old secondary

forest (assumed to be proportional to that registered for primary forest), then recently cleared area in the forested portion of the Legal Amazon is 267,969 km^2, or 6.4% of the forest (Table 2, Columns E & I). In the case of Acre, the result of linear projection from 1987 data (Table 3, Column D) is used in preference to the INPE result because of unexplained discrepancy between the results from the INPE study and the previous IBDF study for that state (see Appendix: Acre).

No direct measurement exists of clearing by 1988 in the savannah areas. An approximation of cerrado area cleared can be obtained by assuming that cerrado within each state is cleared at a rate proportional to the fraction of forest that is cleared (Table 2, Column G). This procedure can be expected to yield a conservative estimate for clearing in cerrado because, in general, these savannahs have been cleared more rapidly than forest areas--simply because cerrado is located along the southern fringe of the region, where entry of population and conversion to agriculture and ranching are concentrated. Cerrado is also easier to clear than forest, and on large ranches in Mato Grosso is often cleared using two bulldozers with a chain dragged between them--a technique that cannot be used in forest. The cerrado in Mato Grosso also suffers from the market for charcoal created by Brazil's iron and steel industry in the Central-South part of the country.

Partially compensating for heavy pressure on cerrado is the clearing behavior of farmers and ranchers with properties astride the irregular boundary between forest and cerrado. LANDSAT imagery shows that within each property, clearing takes place first in the forest (Dicks, 1982).

The assumption that clearing in forest and savannah portions of each state occurs in proportion to the areas present is far from ideal, but is better than alternative assumptions. One alternative assumption is that clearing in the cerrado portion of each state continued (since the previous available deforestation rate data) at the same rate observed for vegetation of all types in that state. In Mato Grosso, the assumption of proportionately equal clearing rates probably underestimates cerrado clearing, but in the remaining three states the opposite is likely. In Rondônia, most of the savannah is spared by being located in an Amerindian reserve. All of the savannah in Roraima and over half the savannah in Pará is humid savannah rather than dry cerrado: these humid savannah areas are often used for cattle or buffalo grazing without being cleared. Conversion of cerrado to pasture is assumed to be taking place in all the savannah regions of Maranhão, Mato Grosso and Tocantins/Goiás, and in one-third of the savannah in Pará (corresponding to areas in the southern part of the state).

By the "best estimate" calculation outlined above, the

cleared area in the Legal Amazon totals 460 X 10^3 km^2, 268 X 10^3 km^2 (58%) of which is forest (Table 2, Column F). Of the original vegetation cover, 9.6% of the total and 6.4% of the forest was cleared in the 1960-1988 period (Table 2, Column I). These values do not include "old clearings" (clearings made prior to 1960, which the INPE/Our Nature Program measurements registered as 31,822 km^2 in Pará and 60,724 km^2 in Maranhão). These older secondary forests were not detected in the earlier LANDSAT-MSS studies (see Fearnside, 1982), and so cannot be used in the present study for the purpose of establishing trends by comparison with older data. The area that has lost its original forest cover, including the old secondary forest area, is an area the size of Finland: 345 X 10^3 km^2, or 8.2% of the original forest area (Table 2, Column N).

The above values for the Legal Amazon can be compared with the result of linear projections in all nine states from the most recent satellite data available prior to the INPE/Our Nature Program estimate. Such projections would indicate 399,765 km^2 cleared by 1988, or 8.0% of the region (Table 1, Columns B & H) (Fearnside, 1990a). Were the clearing figures from the INPE/Our Nature Program estimate used for all nine states, with corrections made for the proportion of the area in forest, the total area cleared would be 572,917 km^2 or 11.5% of the Legal Amazon using the areas of the political units used in the report. Like the "best estimate" calculation, the assumption of proportional cerrado clearing in each state, especially Tocantins/Goiás, leads to the substantial increase in total cleared area when the cerrado is included. More reliable would be comparison of forest areas only: if the forest to savannah proportions of the INPE/Our Nature Program hold, then the "best estimate" value of 267,969 km^2 (6.4% of the forest) would be compared to a value from linear projections of 399,765 km^2 (8.4% of the forest) and the INPE/Our Nature Program's 251,430 km^2 (6.0% of the forest).

The average rate of deforestation can be conservatively estimated by assuming constant rates since the last available satellite measurement of cleared area (Table 3). This procedure underestimates the current rate of deforestation, because the calculation averages deforestation over the period between the last two available satellite measurements while all evidence indicates that areas cleared have, in general, been increasing every year. An exception to this trend may be clearing in 1989, when the number of fires registered on AVHRR infra-red imagery interpreted at INPE was less than in the previous two years. The amount of smoke and observable fire was noticeably less during the 1989 dry season, lending support to the conclusion of lower deforestation that year. An important reason for reduced burning is that substantially more rain than usual fell during the dry season in much of the region (for example, at the INPA research station in Ouro Preto do Oeste, Rondônia, the amount of rain

registered during the first four months of the dry season -- May through August -- was four times greater in 1989 than in 1988: 110.6 mm vs. 26.4 mm. For the full May-October dry season, precipitation was three times greater in 1989: 391.4 mm vs. 131.8 mm). Some reduction in burning may also be due to a campaign by IBAMA to fine those who burn without a newly-required burning permit. These reasons give little grounds to expect that the 1989 reduction indicates that the trend to increased clearing has changed. The deterrent effect of the fines is likely to diminish in the future since none of the money owed by the fined landowners had been collected eight months after the repression campaign began.

The rate of deforestation has been climbing steadily in the decades following the inauguration of the Transamazon Highway in 1970, the event that marks the beginning of the current era of rapid development in the Brazilian Amazon. The increasing rate of clearing renders obsolete the many greenhouse effect calculations that have been based on deforestation estimates for 1980 or earlier. The rapid increase in felling dramatizes the urgency of strong and swift government policy changes to slow the process--by removing the motives for deforestation.

More important than the question of whether 5% or 8% of the Legal Amazon has been deforested is the conclusion that is drawn from the estimate. President Sarney concluded from the INPE study, in his speech unveiling the Our Nature Program, that the data show that deforestation during his administration was "infinitesimal." Unfortunately, this assertion was incorrect regardless of which estimate is used. By the present estimate, a total of 156,967 km^2 (83,965 km^2 of primary forest + 73,002 km^2 of cerrado) had taken place up to that time (April 1989) since President Sarney's Administration began in March 1985. This clearing represents 29.1% of the 539,452 total for clearing of original vegetation (255,141 km^2 of recently cleared primary forest + 92,546 km^2 of pre-1960 forest clearings + 191,765 km^2 of cerrado clearings). All the estimates, including the INPE/Our Nature Program estimate, indicate that deforestation is still raging out of control, and that the government must take strong steps to slow the process. To be effective, these steps must go beyond trying to enforce a prohibition of deforestation to addressing the root causes of rapid clearing, including land speculation, establishment of land tenure, fiscal incentives, and migration to Amazonia for lack of acceptable employment alternatives (Fearnside, 1987, 1989).

APPENDIX
DATA FROM AMAZONIAN STATES

Acre

The INPE study claims that only 5,509 km^2 (or 3.6%) of the state of Acre had been deforested by 1988. This is inconsistent

with the 8,133 km^2 (5.3%) that a study by the Brazilian Institute of Forestry Development (IBDF) showed as deforested by 1987: it implies that 2,623 km^2 of forest had reappeared. The IBDF study of 1987 images also used LANDSAT-TM, so differences in characteristics of the sensor probably do not explain this discrepancy. One possible explanation suggested by the head of the INPE team might be a difference in interpreting the approximately 30,000 km^2 bamboo area in Acre (R.P. da Cunha, personal communication, 20 April 1989). However, all of Acre was originally classified as forest in the INPE report (see Figure 1). Another explanation offered by the INPE group is differences in the scale of images used for the different estimates (R.P. da Cunha, public statement, 29 August 1989). This interpretation is apparently based on the mistaken belief that studies prior to the INPE/Our Nature Program estimate were all done with images at a scale of 1: 500,000. Actually, only the studies of 1975 and 1978 deforestation used images at this scale; later studies used the same 1: 250,000 scale as the INPE/Our Nature Program estimate. In any case, a difference of almost 60% is difficult to explain by this factor alone. In general, more detailed mapping should result in higher, rather than lower, values for deforestation because smaller clearings are missed on the less detailed maps.

Another IBDF deforestation estimate, this one for 1980, is passed over in the INPE report, although included as a stray point on the graph of increasing deforestation in the state (Brazil, INPE, 1989a: 43; da Cunha, 1989: 256). The curve is not drawn through the point indicating the 4,625 km^2 (cited as 4,627 km^2 on the INPE graph) that IBDF's study of 1980 LANDSAT images had shown as deforested (Brazil, IBDF, 1982a). Instead, the curve is shown as a straight line from the 1978 value, thereby hiding the unrealistic implication that only 885 km^2 had been cleared in Acre over the 1980-1988 period--something obviously false to anyone who had visited the area during those years of explosive deforestation. The discrepant point is simply omitted from the graph in the second edition of the report (Brazil, INPE, 1989b: 34).

One difference that may explain part of the discrepancy between the INPE and IBDF results in Acre is the treatment of old clearings where secondary forests are difficult to distinguish from virgin forest on the images from the nominal year of the estimate. INPE considered as deforested whatever appeared altered on the images used (for Acre: parts of 3 images from 1988 and 5 images from 1987, Tardin and da Cunha, 1989: 12). IBDF identified older secondary forest areas in Acre using LANDSAT-MSS images from 1975, 1978 and 1982 (Marisa Terezinha Pereira, personal communication, 1989; Brazil, IBDF, 1988a: 25). How much of the deforestation registered for Acre was detected using the older images is not given in the report. Regardless of the amount, the difference in methodology for old secondary forest can only explain a portion of the 2,623 km^2 discrepancy: the

difference between the INPE and IBDF values is larger than the 2,465 km^2 total that had been deforested in the state by 1978 and over twice the 1,166 km^2 that had been deforested by 1975 (Tardin et al., 1980; see Fearnside, 1984: 44).

The omission of images from central Acre (Figure 2) could also explain part of the discrepancy. However, the discrepancy is so large that the omitted images are unlikely to account for these differences.

Amapá

Amapá has long been one of the political units with the lowest rate of increase in deforested area (e.g., Fearnside, 1982). The INPE/Our Nature Program study shows a total of 842 km^2 (0.6%), somewhat more clearing than would have occurred by continuation of the 1975-1978 trend, and represents the best data available for Amapá (Table 2, Column H). Prior to the INPE report, the most recent data are from 1978 (Brazil, IBDF, 1983c). The heavy cloud cover usually present over Amapá has discouraged LANDSAT measurements, while AVHRR measurements have omitted this state because areas north of the equator are not included on the AVHRR scene that covers most of Amazonia.

Amazonas

Amazonas has very little deforestation so far. Most is concentrated either in the Manaus area or near Boca do Acre. The INPE/Our Nature Program estimate of 12,837 km^2 or 0.8% deforested by 1988 is the best available for this state (Table 2, Column H), which has no other satellite measurement since 1978. Linear projection from 1978 would imply 0.3% deforested. In 1989, IBAMA initiated a project in collaboration with SUDAM technicians to interpret LANDSAT-TM images from Amazonas for 1987, but results are not yet available.

Maranhão

Maranhão is the most heavily deforested state. Recent clearing in Maranhão totals 54,803 km^2 (including the re-cutting of old secondary forest as well as original forest and cerrado (Table 2, Column H). Of this, 20,664 km^2 is cerrado clearing and 10,369 km^2 is proportional clearing in the 60,724 km^2 of old secondary forest present in the state. The remaining 23,771 km^2 represents recent clearing in virgin forest. The total loss of original forest is 60,724 km^2 of old, plus 23,771 km^2 of recent loss, or 84,495 km^2 (Table 1, Column G). Of 139,215 km^2 of original forest, this represents 60.7% (Table 2, Column M).

Mato Grosso

In the case of the state of Mato Grosso, INPE reports 67,216

km^2 of forest as cleared by 1988 (11.7% of the original forest, Table 2, Column E). The graph of deforested area is shown rising gently from a level of 59,183 km^2 in 1983, citing IBDF for the latter figure (NB: the implication of slow deforestation is invalid, since the INPE/Our Nature Program value refers only to forest while the previous estimates are for all vegetation types). How the value attributed to IBDF for 1983 was derived is unclear, since the 1983 LANDSAT images in Mato Grosso interpreted by that agency (Brazil, IBDF, 1985) cover only the western half of the state where the World Bank-financed POLONOROESTE Project paid for interpretation, and found only 24,281 km^2 deforested there. An estimate for the entire state using the IBDF estimate for the western half, and a linear projection from the statewide deforestation rate in the 1978-1980 period for the eastern portion (data from Brazil, IBDF, 1982b), calculates 89,903 km^2 as cleared by 1983 (Fearnside, 1990a). These figures would imply that the deforested area shrank by 27,687 km^2 between 1983 and 1988, but omission of cerrado from the INPE/Our Nature Program estimate can explain the apparent decrease. The location of fires during this period detected by AVHRR infra-red images (Setzer et al., 1988) shows Mato Grosso as one of the principal foci of deforestation in Amazonia.

Another factor contributing to discrepancies among estimates for Mato Grosso is use of differing numbers for the area of the state in the Legal Amazon. The INPE/Our Nature Program estimate used 802,408 km^2 as the area of Mato Grosso in the Legal Amazon. This area refers to that in effect from creation of the Legal Amazon in 1953 until 1977, when the former state of Mato Grosso was divided into Mato Grosso do Sul and the present state of Mato Grosso. The Legal Amazon currently encompasses the entire present state of Mato Grosso (881,001 km^2), and this larger area has been used by all other deforestation estimates using images from 1980 onwards (beginning with Brazil, IBDF, 1983a). If cerrado were cleared in the same proportion as forest, then the total cleared area in the state would be 103,400 km^2, or 12.9% of the area used by the INPE/Our Nature Program estimates within the Legal Amazon. Adjusting the INPE/Our Nature Program results proportionately for the larger state area would bring the total clearing to 113,538 km^2 (12.9%) for all vegetation types. The additional area added to the Legal Amazon in Mato Grosso is virtually all cerrado vegetation.

The likelihood that only 59,183 km^2 had been deforested in Mato Grosso by 1983 (the IBAMA estimate cited by the INPE/Our Nature Program report) is low if the 1980 estimate of 52,786 km^2 (Brazil, IBDF, 1982b) is correct, since the implied average deforestation rate of 2,132 km^2/year in the 1980-1983 period is improbable, given that the corresponding deforestation rate for the 1978-1980 period was 11,208 km^2/year.

Mato Grosso is one of the most difficult states to interpret

because of the complex of fingers and islands of forest that forms the border between forest and cerrado vegetation in this state. A study of AVHRR imagery from 1985 provides some evidence that the area of forest cleared is less than that derived from linear projections, but, like the INPE/Our Nature Program study, interpretation is made difficult by lack of reporting of criteria used to define original vegetation types and their respective areas. The study measured 56,646 km^2 deforested in the "phytogeographically Amazonian" portion of Mato Grosso (Malingreau and Tucker, 1988: 53). If one assumes that "phytogeographically Amazonian" refers to forest as mapped in the INPE/Our Nature Program report, then 9.9% of the forest in Mato Grosso was deforested by 1985; if clearing in cerrado was proportional to that in forest, then a total of 87,148 km^2 (9.9% of the area of the state) had been cleared by that year. This implies that area cleared had declined by 2,755 km^2 between 1983 and 1985 if the 1983 estimate is correct. If one assumes that the 1983 estimate is not correct, then linear projection from the 1980 and 1985 data would yield a 1988 clearing figure of 107,765 km^2 of the area originally under either forest or cerrado (the clearing would represent 12.2% of the state); 70,074 km^2 of this clearing is in the forested portion of the state.

Because available data for Mato Grosso are conflicting, it should be borne in mind that the value used for deforestation in this state is highly uncertain. Obtaining a time series for clearing measurements with consistently applied criteria for vegetation classification is particularly urgent for this state. The clearing values for 1988 in Mato Grosso may well change as better information becomes available.

Pará

In Pará, the INPE report claims that only 88,741 km^2 of forest had been cleared by 1988 (Table 1, Column C). An estimate made by IBDF technicians working in SUDAM using 1986 LANDSAT-TM images had found that 114,770 km^2 of the state (all vegetation types) had been cleared by 1986. Adjusting the 1988 forest clearing value, assuming the same proportion of clearing in other vegetation types, would increase the total to 93,767 km^2 for comparison with the 114,770 km^2 SUDAM/IBDF value (7.5% of the state). INPE explains the discrepancy between its value of 88 X 10^3 km^2 and the 114 X 10^3 km^2 SUDAM/IBDF value as being due to "very old deforestation" having been included in the latter study but not in the INPE study (Brazil, INPE, 1989a: 46). However, both studies used LANDSAT-TM imagery, counting as "deforested" the areas that appeared bare in the images. In the IBDF study, black and white images of LANDSAT-TM bands 3, 4 and 5 were used at a scale of 1: 250,000. In the INPE study the areas selected for examination at the 1: 250,000 scale were analyzed using false color composites of the same three bands (Brazil, INPE, 1989a: 11). The technique used by IBDF is not capable of distinguishing

between old secondary forest and virgin forest. This limitation is made plain by INPE's earlier results obtained using the same technique with LANDSAT-MSS images from 1975: the older cleared areas known to exist in Pará's Zona Bragantina are larger than the area indicated by INPE (Tardin et al., 1980) as cleared by 1975 in the entire Legal Amazon (see Fearnside, 1982).

These methodological limitations make it likely that the IBDF estimate for 1986 underestimates deforestation. INPE's decision to discard the IBDF 1986 estimate as overstating deforestation is therefore questionable. INPE's graph for Pará (Brazil, INPE, 1989a: 46) shows an estimate of 120,563 km^2 for 1988 deforestation including old clearings, but uses the lower value of 88,741 km^2 as the "real value for 1988" (amended to "value obtained for 1988" in the second edition of the report). The lower value is used in computing the 5% deforestation overall total for the Legal Amazon. Exclusion of older deforestation from this total is inconsistent with President Sarney's presentation of the 5% value as the total cleared "since Cabral discovered Brazil." Clearing between 1960 and 1988 resulted in 92,922 km^2 lost (Table 2, Column H); adding 31,822 km^2 of old clearing would bring the total to 124,744 km^2.

Rondônia

In Rondônia, the INPE/Our Nature Program report indicates 30,046 km^2 of forest was cleared by 1988 (Table 2, Column C). Adjusting this for proportional clearing in savannah would yield a total of 31,016 km^2, and adjusting for different values used for the area of the state would bring total clearing to 31,623 km^2 (13.0% of the state) (Table 1, Column D). The adjustment for savannah assumes that only 25% of savannah area indicated on the INPE map (Figure 1) is exposed to clearing: the remainder is located in two Amerindian reserves (NB: although some illegal clearing has occurred in Amerindian reserves in Rondônia, it has so far been in forested areas). The cerrado clearing (989 km^2, adjusted for state area) is conservative given the widespread conversion of this vegetation type to pasture and soybean cultivation near Vilhena in eastern Rondônia.

The INPE/Our Nature Program estimate for Rondônia is inconsistent with information derived from AVHRR. Although better correction factors may eventually resolve the discrepancy, no adequate explanation is currently available. AVHRR indicated 39,600 km^2 (15.1% of the state) as cleared by 1987 (J.P. Malingreau, personal communication, 1988). An AVHRR image from 1985 had indicated 27,658 km^2 (11.3% of the 243,044 km^2 state area)[3] (Malingreau and Tucker, 1988). A linear projection from the 1985 and 1987 AVHRR estimates would yield a deforested area of 41,521 km^2 (17.1% of the state) by 1988 (Table 1, Columns B & H) (Fearnside, 1990a).

The much coarser resolution of AVHRR as compared to LANDSAT makes AVHRR less reliable. It may be, therefore, that the difference in results is explained by differences between the two sensors. INPE bolsters its claim of lower deforestation in Rondônia by citing an estimate for 1986 of 22,913 km^2 made by the Brazilian Institute for Environment and Renewable Natural Resources (IBAMA).(4) The head of the INPE team states that the 1986 value was supplied in a telex from Fernando Cesar Mesquita, director of IBAMA (R.P. da Cunha, personal communication, 20 April 1989). A subsequent IBAMA report indicates that the 22,913 km^2 deforestation value refers to 1987 rather than 1986 LANDSAT images (Brazil, IBDF, 1989), thereby increasing even further the discrepancy with previous results.

The data on deforestation in Rondônia are confusing, to say the least. Part of the discrepancy between the various existing studies may be due to over or under estimation inherent in the technique used for each study. AVHRR 1.1 km resolution data have been reported to underestimate deforestation by 2-18% when applied to Rondônia, but uncertainties in the adjustments made for comparing LANDSAT-TM to AVHRR images from different years led the authors of the study to conclude that a correction factor of 1.0 (i.e., leaving results unchanged) was appropriate (Woodwell et al., 1984: 252). This group continued to find good agreement between LANDSAT and AVHRR in Rondônia (Woodwell et al., 1987), but now believes that AVHRR is overestimating deforestation (I. Foster Brown, personal communication, 1989). Other published AVHRR estimates for Rondônia have assumed that a correction factor is unnecessary (Malingreau and Tucker, 1988; Tucker et al., 1984). Comparison of 10 meter resolution data from the SPOT satellite with a simulated AVHRR image produced by degrading the SPOT data to the 1.1 km resolution of AVHRR has resulted in a value of 18% as the correction factor for overestimation by AVHRR under the conditions prevailing in Rondônia (David Skole, INPA seminar, 1989). Overestimation by AVHRR would be greater in Rondônia than in areas such as Mato Grosso where large ranches dominate deforestation. The long narrow strips of clearing that characterize the "fish bone" pattern of small-farmer settlements in Rondônia would introduce bias because of a predominance of sub-pixel width clearings that are sufficiently large to trigger the entire pixel.

LANDSAT studies such as those available for Rondônia for 1975, 1978, 1980, 1983, 1987 and 1988 images would also produce biased results, but in the opposite direction. All of these studies used manual interpretation of paper photographic products, rather than computer aided analysis of digital tapes. Small clearings are underestimated using manual methods, with greater error at larger map scales. The studies with images from 1975 and 1978 used 1: 500,000 images, while the later studies used 1: 250,000 images. No information is available to correct for biases in the manual methods used. The resolution of the

sensors also varies: estimates for 1983 and earlier used the multispectral scanner (MSS) with 80 m resolution, while the more recent estimates used the thematic mapper (TM) with 30 m resolution.

If one uses only LANDSAT data, the trend in deforestation rates in Rondônia is consistent except for an improbably high jump from 1987 to 1988 (Figures 4 and 5). LANDSAT studies have found 1,217 km^2 (0.5% of the state) cleared by 1975 and 4,185 km^2 (1.7% of the state) cleared by 1978 (Tardin et al., 1980); 7,579 km^2 (3.1% of the state) cleared by 1980 (Brazil, IBDF, 1983a); 13,955 km^2 (5.7% of the state) cleared by 1983 (Brazil, IBDF, 1985); 22,913 km^2 (9.4% of the state) cleared by 1987 (Brazil, IBDF, 1989), and 31,623 km^2 (13.0% of the state) cleared by 1988 (Brazil, INPE, 1989a,b corrected for savannah clearing and state area; see Table 2, Column H). These clearing estimates imply rates of deforestation climbing from less than 243 km^2/year[5] in 1970-1975 to 989 km^2/year in 1975-1978, to 1,697 km^2/year in 1978-1980, to 2,125 km^2/year in 1980-1983, to 2,167 km^2/year for 1983-1987, followed by a tremendous jump to 8,437 km^2/year for 1987-1988 (Figure 5).

If one uses results from AVHRR corrected by a factor of 18% to adjust for overestimation and with an additional correction for cerrado clearing to make the values comparable to the LANDSAT studies (all LANDSAT studies included cerrado with the exception of that for 1988; AVHRR studies excluded cerrado), the deforested area in Rondônia reached 9,973 km^2 (4.1% of the state) by 1982 (calculated from Woodwell et al., 1984: 252), 24,195 km^2 (10.0% of the state) by 1985 (calculated from Malingreau and Tucker, 1988), and 32,280 km^2 (13.3% of the state) by 1987 (calculated from Malingreau, personal communication, 1988) (Figure 4). A linear projection to 1988 would indicate 36,323 km^2 (14.9% of the state) as deforested. The implied clearing rates would indicate a drop from the LANDSAT-based rate of 1,697 km^2/year for 1978-1980 to 1,197 km^2/year for 1980-1982, followed by a jump to 4,741 km^2/year for 1982-1985, falling to 4,042 km^2/year for 1985-1987 (Figure 5).

More information will be needed to evaluate the 9,898 km^2 discrepancy between the INPE estimate for Rondônia (adjusted for savannah and state area) and the uncorrected AVHRR-based estimate, or the 4,700 km^2 discrepancy with the corrected AVHRR-based estimate. The discrepancy with uncorrected AVHRR is 31.3%, falling to 14.9% when the corrected AVHRR value is used. Although the difference is substantial for this state, Rondônia's relatively small area (about 5% of the Legal Amazon) means that the discrepancy weighs little in the total for the Amazon region. The present study will use the more conservative INPE value (with the adjustments for savannah and for state area).

Roraima

INPE's estimate for forest clearing by 1988 in Roraima is 2,187 km^2, or 1.0% (Table 1, Column C). The previous estimates for Roraima shown in the INPE report's graph of the growth of deforested area (Brazil, INPE, 1989a: 48) omit the estimate for 1981 LANDSAT images(6) made by IBDF (Brazil, IBDF, 1983b). Taking into account the 1,170 km^2 indicated by the IBDF estimate, it appears improbable that only 1,017 km^2 were cleared over the seven year period between 1981 and 1988. This was the period during which the National Institute for Colonization and Agrarian Reform (INCRA) established Apiaú, São Luis and other official colonization projects that are clearly visible on the 1986 images in INPE's mosaic of the northern region (Brazil, INPE, 1988). Nevertheless, the present study uses the INPE/Our Nature Program value for clearing by 1988 in Roraima (Table 2, Column F).

Tocantins/Goiás

Tocantins/Goiás(7) is the political unit where results are least satisfactory for estimating cerrado clearing rates based on the INPE measurements of forest clearing. This state has only a narrow sliver of forest along its northwestern edge. The INPE/Our Nature Program study indicates a high percentage (63.3%) of the forest has been cleared (Table 1, Column J); by assuming that the same percentage applies to the cerrado, a large area (171 X 10^3 km^2) is estimated to have been cleared (Table 1, Column D). Continuation of the previous trend would imply only 9% cleared. The extensive deforestation apparent to any visitor to Tocantins makes the higher figure likely to be correct, but the low level of certainty should be borne in mind. Any error in INPE's mapping of original vegetation would produce a large effect on clearing percentage values for forest in this case, and thereby affect the cerrado cleared area estimate. As will be explained later, estimates of the original area present are unreliable, despite being the best available. Because cerrado is the original vegetation type for a large proportion of Tocantins/Goiás, uncertainty in drawing the cerrado/forest boundary has its greatest effect on the total for the Legal Amazon in the values for savannah clearing. By assuming clearing in the Tocantins/Goiás cerrado proportional to that indicated by the INPE study for the forest, this would contribute 80,730 km^2 to the cerrado clearing total. However, a more conservative assumption is made in the present estimate.

The assumption used in the current "best estimate" is that the INPE map does not reflect the criteria really used in the deforestation estimate for the Tocantins/Goiás area. IBGE data (reproduced in Benchimol, 1989: 56) indicate that the entire states of Tocantins and Goiás jointly contain 31,916 km^2 of Amazonian terra firme humid forest, plus 68,573 km^2 of "sub-humid forest of the interior". The value for terra firme forest area is almost exactly the same as that indicated by the INPE map

(32,056 km^2), and can be considered identical given the wide margin of error for the forest area estimates. The sub-humid forest is also likely to be located in the portion of this two-state area that is within the Legal Amazon (i.e., in "Tocantins/Goiás"). If one uses the sum of these two forest types (100,629 km^2) as the forest area for Tocantins/Goiás, then the percentage represented by the 20,279 km^2 that the INPE study found deforested falls to 20.2% (Table 2, Column I). Proportional clearing in the cerrado, assumed to occupy the remaining 169,282 km^2 of Tocantins/Goiás, would be 34,114 km^2. These lower numbers are used in the present estimate (Table 2, Column G).

That doubt could exist as to whether a state is 20% or 63% deforested indicates the low reliability of the estimates. Fortunately, Tocantins/Goiás weighs little in the total for Amazonia because of its small geographical area.

NOTES

(1) Myers (1989: 15) backs up his figure of 50,000 km^2/year for the current rate of forest loss with a historical series of deforested areas. However, most of the figures given are from sources that have included the cerrado in the deforestation estimates (e.g. Fearnside, 1990a; Mahar, 1989), although cerrado does not fit the definition of "forest" used in the report (pp. 4-5) and would be inconsistent with the figures given for forest area (p. 7). The series of deforested areas for 1980, 1985 and 1987 in the Brazilian Legal Amazon (p. 15) all include cerrado, although they are described in the report as "forest" (p. 15). Some of the sources cited have excluded the cerrado (e.g. Malingreau and Tucker, 1988 and Woodwell et al., 1987), but in these cases the studies only cover one or two of the nine states in the region. In the case of Acre (p. 15), the origin of the 1988 value of "almost 20,000 sq. kms." attributed to Malingreau and Tucker (1988) is not clear. Malingreau and Tucker's paper only presents data for 1985, for which year they found only 5269 km^2 of deforestation in Acre.

(2) Calculated using area of original vegetation of Legal Amazon as in Table 1. Mahar reports percentage as 11.7%.

(3) INPE uses an area of 238,739 km^2 for Rondônia (Brazil, INPE, 1989a,b).

(4) IBAMA was created in January 1989, and incorporates the former Brazilian Institute for Forestry Development (IBDF). From January to April 1989, IBAMA was known as IBMARNR.

(5) This deforestation rate assumes that there was no clearing prior to 1970--an assumption that, while clearly false, makes the upsurge of deforestation appear less explosive in the early 1970s

than it really was (see Fearnside, 1986).

(6) The IBDF report uses 1982 as the nominal year for the estimate, but most images are from 1981 (see Fearnside, 1990a).

(7) The term "Tocantins/Goiás" is used by INPE (Brazil, INPE, 1989a,b) to refer to portions of the states of Tocantins and Goiás north of 13^{o} S. latitude--the limit of the "Legal Amazon" in this area. Tocantins was created by Brazil's October 1987 constitution from the northern half of the former state of Goiás. The border between Tocantins and the present state of Goiás is an irregular line zig-zagging along the 13th parallel, leaving a small part of Tocantins out of the Legal Amazon and a small part of Goiás inside this administrative unit.

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SUMMARY

Examination of the often contradictory estimates of the rate and extent of deforestation in Brazilian Amazonia leads to a "best estimate" of the cumulative area of forest cleared through 1988 as 345 X 10^3 km^2 (including old clearings), or 8.2% of the 4 X 10^6 km^2 forested portion of Brazil's 5 X 10^6 km^2 Legal Amazon region. Recent (post-1960) clearing of primary and old secondary forest totaled 268 X 10^3 km^2, or 6.4%. Including clearing in the cerrado increases the total of recent clearing to 460 X 10^3 km^2, or 9.6% of the area originally under forest and cerrado. Forest loss in 1988 was proceeding at 20 X 10^3 km^2/ year; inclusion of estimated cerrado loss raises the total to 39 X 10^6 km^2/year, an area almost the size of Holland.

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FIGURE LEGENDS

Figure 1 - Forest and savannah in the Brazilian Legal Amazon (redrawn from Brazil, INPE, 1989a).

Figure 2 - Dates of LANDSAT images used for the INPE/Our Nature Program estimate of deforestation through 1988. (redrawn from Tardin and da Cunha, 1989).

Figure 3 - Deforested areas in the states of the Brazilian Legal Amazon, based on LANDSAT data (see text for data references).

Figure 4 - Deforested areas in the state of Rondônia, based on LANDSAT and corrected AVHRR data. The absolute value for 1988 derived from LANDSAT was considered to be more reliable than that from AVHRR (Source: Fearnside, 1990b).

Figure 5 - Rates of deforestation in the state of Rondônia based on LANDSAT and corrected AVHRR data. The 1988 rate derived from AVHRR was considered to be more reliable (Source: Fearnside, 1990b).

TABLE 1: COMPARISON OF DIFFERENT ESTIMATES OF CLEARED AR

State	Area of recent (post-1960) clearing			
	Fearnside, 1990a	Brazil, INPE, 1989a[a] as re-ported	Brazil, INPE, 1989b[b] with cor-rections	Mahar, 1989
----A----------	-----B----	----C---	----D----	----E---
Acre	8,634	5,510	5,510	19,500
Amapá	231	842	842	572
Amazonas	5,150	12,837	12,837	105,790
Maranhão	24,019	23,771	54,803	50,670
Mato Grosso	151,766	67,216	201,493	208,000
Pará	148,111	88,741	92,922	120,000
Rondônia	41,521	30,046	31,623[e]	58,000
Roraima	3,565	2,187	2,187	3,270
Tocantins/Goiás	16,768	20,279	170,700	33,120
Legal Amazon (forest+cerrado)	399,765	251,429	572,917	598,922
Legal Amazon (forest only)		251,429	295,432	

(Table 1, part 2)

EA BY 1988

(km^2) Current best estimate	Area of original primary forest cleared (km^2)[d] (recent + old clearings)	Percentage of political unit[c] Fearnside, 1990a	Brazil, INPE, 1989a[a] as reported	Brazil, INPE, 1989b[b] with corrections	Mahar, 1989
8,634	8,634	5.7	3.6	3.6	12.8
842	842	0.2	0.6	0.6	0.4
12,837	12,837	0.3	0.8	0.8	6.8
54,803	84,495	9.3	9.1	21.1	19.7
201,493	67,216	17.2	8.4	22.9	23.6
92,922	118,150	12.1	7.1	7.5	9.6
31,623	30,634[e]	17.1	12.6	13.0	23.7
2,187	2,187	1.6	1.0	1.0	1.4
54,393	20,279	5.9	7.5	63.2	11.6
459,734		8.0	5.1	11.5	12.0
267,969	345,274			7.0	

(Table 1, part 3)

Best estimate for comparison with percentages of political units	BEST ESTIMATE FOR RECENT DEFORESTATION (percentage of primary forest, old second growth and cerrado cut since 1960)	BEST ESTIMATE FOR TOTAL DEFORESTATION (percentage of original primary forest cut[d]
5.7	5.7	5.7
0.6	0.8	0.8
0.8	0.8	0.8
21.1	21.1	60.7
22.9	24.9	11.7
7.5	7.7	10.0
13.0	13.0	14.2
1.0	1.3	1.3
20.2	20.2	20.2
9.2	9.6	
	6.4	8.2

(Table 1, notes)

(a) Areas and percentages as reported in Brazil, INPE, 1989a. The second version of the report (Brazil, INPE, 1989b) indicates that the areas refer only to forest clearing while the denominators used in calculating the percentages refer to the areas of political units, including savannah vegetation. Unless otherwise specified, all other values in the table refer to clearing of forest (both primary and old secondary) and cerrado (but not humid savannah). All values in the table refer to recent clearing identifiable by traditional techniques for satellite image interpretation (see text). Areas are adjusted for state area in Rondônia and Mato Grosso, and for clearing in old secondary forests in Pará and Maranhão.

(b) Areas for clearing forest (primary and old secondary) + cerrado estimated assuming that cerrado is cleared in the same proportion reported for forest clearing within each state. In the case of Rondônia, approximately 75% of the cerrado area indicated on the INPE map is inside Amerindian reserves and is assumed to be protected from clearing.

(c) All percentages calculated using the areas of political units adopted by the cited publications.

(d) Old (pre-1960) clearing only included for Pará and Maranhão, as reported by Brazil, INPE, 1989b. Denominator is original area of tropical terra firme (upland) primary forest (humid and subhumid), and does not include cerrado and humid savannah.

(e) Adjusted for state area.

TABLE 2: ORIGINAL VEGETATION AND BEST ESTIMATE OF AREAS IN THE BRAZILIAN LEGAL AMAZON FROM 1960 THROUGH

State	Original Vegetation (km^2)[a]				Recently
	Forest	Cerrado	Humid savannah	Total original vegetation	Forest
	----B----	----C---	----D---	----E----	----F----
Acre	152,589	0	0	152,589	8,634
Amapá	99,525	0	42,834	142,359	842
Amazonas	1,562,488	0	5,465	1,567,953	12,837
Maranhão	139,215	121,017	0	260,232	34,140
Mato Grosso	572,669	235,345	72,987[c]	881,001	67,216
Pará	1,180,004	22,276	44,553	1,246,833	91,200
Rondônia	215,259	27,785	0	243,044	30,634
Roraima	173,282	0	51,735	225,017	2,187
Tocantins/ Goiás	100,629	169,282	0	269,911	20,279
Legal Amazon	4,195,660	575,705	217,574	4,988,939	267,969

(Table 2, part 2)

RECENTLY CLEARED 1988 cleared area(km^2)		Percent recently cleared		Source
Cerrado[b]	Total	Of forest	Of forest + cerrado	
G	H	I	J	K
0	8,634	5.7	5.7	(d)
0	842	0.8	0.8	(e)
0	12,837	0.8	0.8	(e)
20,664	54,803	24.5	21.1	(e)
134,277	201,493	11.7	24.9	(e)
1,722	92,922	7.7	7.7	(e)
989[f]	31,623	14.2	13.0	(e)
0	2,187	1.3	1.3	(e)
34,114	54,393	20.2	20.2	(e)
191,765	459,734	6.4	9.6	

TABLE 2 notes:

(a) Original vegetation in accord with the INPE map (Figure 1), with the savannah areas apportioned between humid savannah and cerrado in their approximate proportions in the savannah areas shown for each state. The forest in Tocantins/Goiás has been increased by 68,573 km^2 presumed to have been included in the INPE survey but not in the map of original vegetation. "Forest" includes both "primary (virgin) forest" and "old secondary forests" (from clearings prior to 1960 in Pará and Maranhão). Totals are areas of political units, including water surfaces, as in the INPE and IBDF reports (making the percentages underestimates). The area of Tocantins/Goiás is that used by Brazil, INPE, 1989a,b; it is at variance with the 235,793 km^2 used in previous INPE reports (e.g., Tardin et al., 1980) for the same geographical area.

(b) Cerrado clearing, which was not measured in the INPE study (Brazil, INPE, 1989b), has been estimated assuming that this vegetation type is cleared in the same proportion as the forest within each state, the exceptions of Rondônia (where proportionality is assumed excluding cerrado areas in Amerindian reserves) and Mato Grosso (where data exist for cerrado clearing in the western part of the state in 1983, and the ratio of cerrado to forest clearing observed there is assumed to apply to the entire state through 1988).

(c) Pantanal (Mato Grosso humid savannah) area from IBGE data reproduced in Benchimol (1989: 56). The remainder of the savannah area in Mato Grosso shown in Figure 1 (with correction for state area) is considered cerrado.

(d) Linear projection from the last two years of available satellite data (see Fearnside, 1990a).

(e) Brazil, INPE, 1989b, with corrections for state areas and cerrado clearing (see appendix).

(f) Rondônia cerrado clearing assumes that 6,946 km^2 of cerrado (25% of the 27,785 km^2 of cerrado in the state according to the INPE map) is exposed to clearing. The remainder is in an Amerindian reserve.

(Table 3, part 1)

TABLE 3: AVERAGE CLEARING RATES IN THE BRAZILIAN LEGAL AM

STATE	Last previous data		
	Year	Source	Clearing total (km
A	B	C	D
Acre	1987	IBDF, 1988b	8,133
Amapá	1978	Tardin et al., 1980	171
Amazonas	1978	Tardin et al., 1980	1,791
Maranhão	1980	IBDF, 1983a	10,671
Mato Grosso	1980	IBDF, 1982b	52,786
Pará	1986	SUDAM/IBDF, 1988	85,203[a]
Rondônia	1987	IBDF, 1989	22,913
Roraima	1981	IDBF, 1983b	1,170
Tocantins/Goiás	1980	IBDF, 1983a	9,120
Legal Amazon			

(Table 3, part 2)

AZON

	Clearing total by 1988 (km^2)	Average clearing rate in 1988 (km^2/year)		
		Forest	Cerrado	Total
[2)]	E	F	G	H
	8,634	501	0	501
	842	67	0	67
	12,837	1,105	0	1,105
	54,803	3,437[a]	2,080	5,517
	201,493	5,580	13,008	18,588
	92,922	3,788	72	3,860
	31,623	3,916[b]	126	4,042
	2,187	145	0	145
	54,393	1,759	2,959	4,718
	459,734	20,298	18,245	38,543

TABLE 3 notes:

(a) Pará and Maranhão clearing include reclearing in the area of old (pre-1960) secondary forest. Old secondary forest zones total 31,822 km^2 in Pará and 60,724 km^2 in Maranhão; of these, an estimated 2,255 km^2 and 2,459 km^2 were cleared by 1986 and 1988 respectively in Pará, and 10,369 km^2 were cleared by 1988 in Maranhão. Estimates in these states for years prior to 1986 had been unable to distinguish the old secondary forest from virgin forest, and the clearing in the old secondary forest region is therefore included without correction. For 1986 and 1988 in Pará and for 1988 in Maranhão, the clearing within the old secondary forest area is assumed to have occurred in the same proportion as that in virgin forest.

(b) Rondônia clearing rate assumed to follow the trend from the 1985-1987 period shown by AVHRR. Uncorrected deforestation values: 27,658 km^2 by 1985 (Malingreau and Tucker, 1988); 36,900 km^2 by 1987 (Jean-Paul Malingreau, personal communication, 1988); corrected for cerrado and 18% adjustment for pixel size effect (based on comparison made by David Skole, University of New Hampshire, Durham, NH, USA, of 10 m resolution SPOT data with SPOT data degraded to 1.1 km resolution to simulate AVHRR): 24,195 km^2 by 1985 and 32,280 km^2 by 1987.

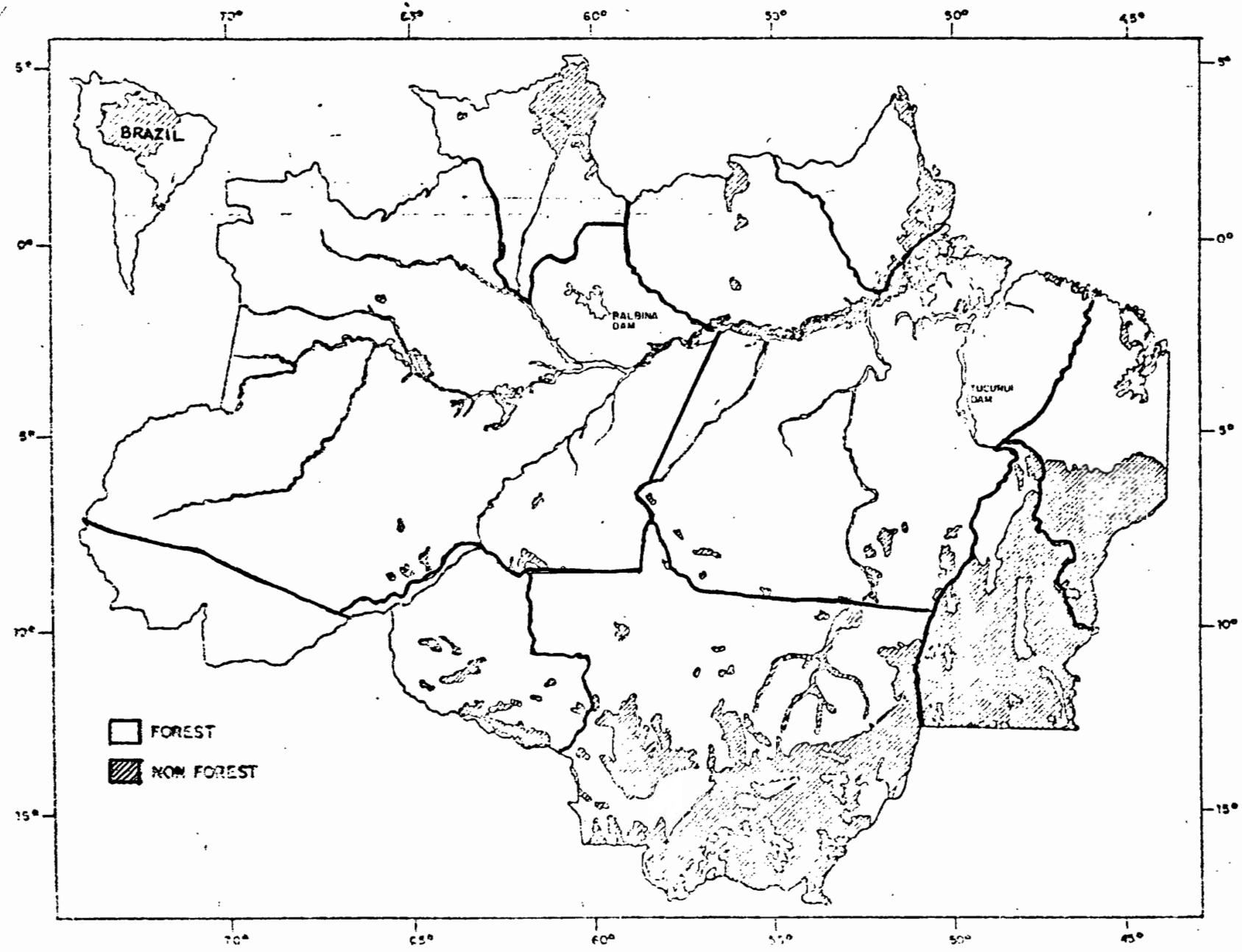

Fig. 1.

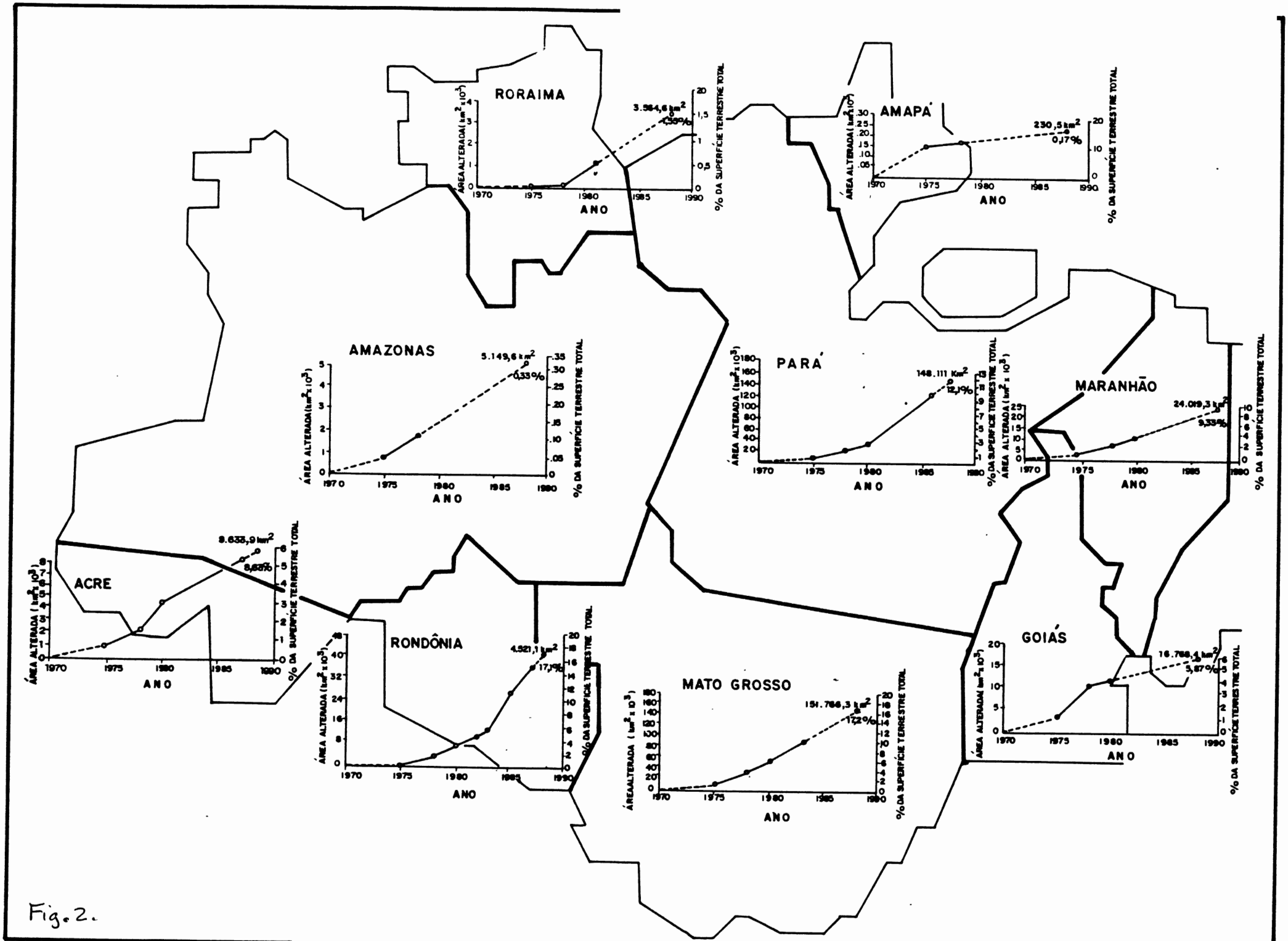
RORAIMA
3.564,6 km²
4,39%
AMAPÁ
230,5 km²
0,17%
AMAZONAS
5.149,6 km²
0,33%
PARÁ
148.111 Km²
12,1%
MARANHÃO
24.019,3 km²
9,33%
ACRE
8.638,9 km²
8,62%
RONDÔNIA
4.521,1 km²
17,7%
MATO GROSSO
151.766,3 km²
12,2%
GOIÁS
16.766,1 km²
5,67%
ÁREA ALTERADA (km² x 10³)
% DA SUPERFÍCIE TERRESTRE TOTAL
ANO
1970
1975
1980
1985
1990

Fig. 2.

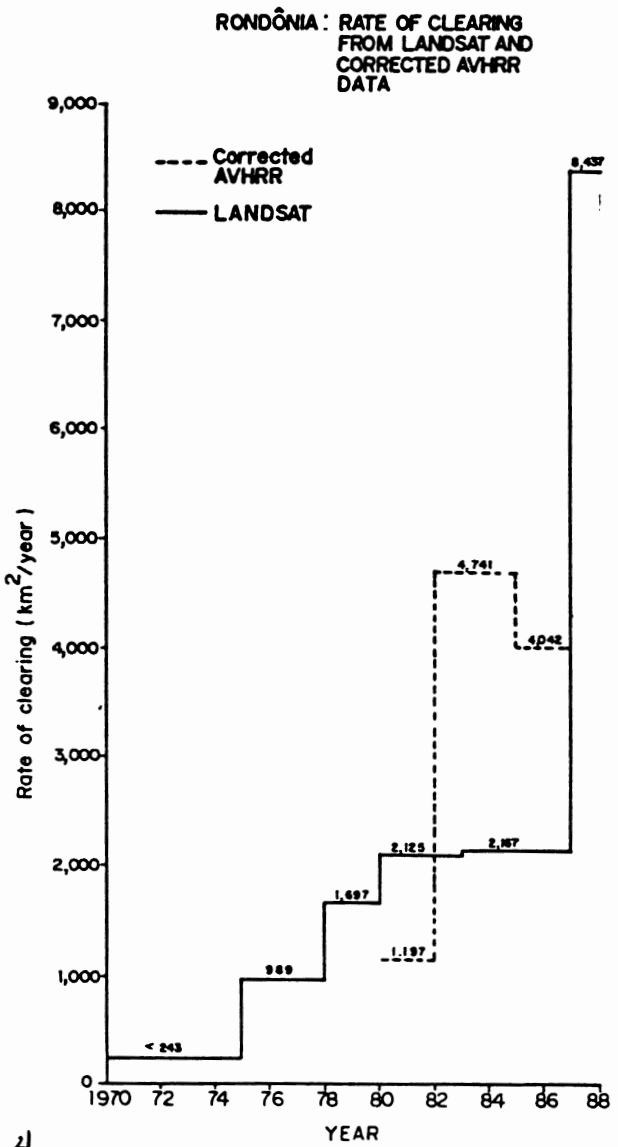
RONDÔNIA: RATE OF CLEARING FROM LANDSAT AND CORRECTED AVHRR DATA
Corrected AVHRR
LANDSAT
Rate of clearing (km²/year)
YEAR
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1970 72 74 76 78 80 82 84 86 88
< 243
989
1,697
2,125
1,197
4,741
4,042
2,167
8,437

Fig. 4.

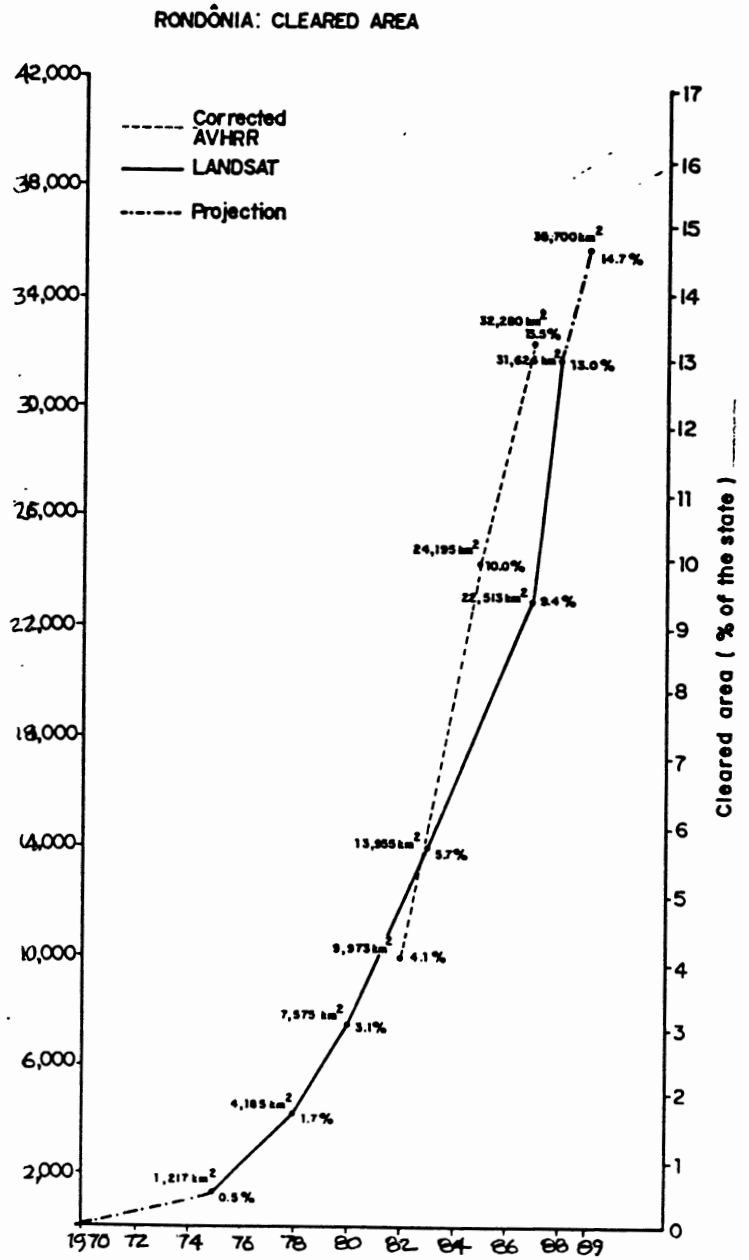
RONDÔNIA: CLEARED AREA
Corrected AVHRR
LANDSAT
Projection
Cleared area (% of the state)
42,000
38,000
34,000
30,000
26,000
22,000
18,000
14,000
10,000
6,000
2,000
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1970 72 74 76 78 80 82 84 86 88 89
1,217 km²
0.5%
4,185 km²
1.7%
7,575 km²
3.1%
9,973 km²
4.1%
13,955 km²
5.7%
22,513 km²
9.4%
24,195 km²
10.0%
31,624 km²
13.0%
32,280 km²
13.5%
36,700 km²
14.7%

Fig. 3.

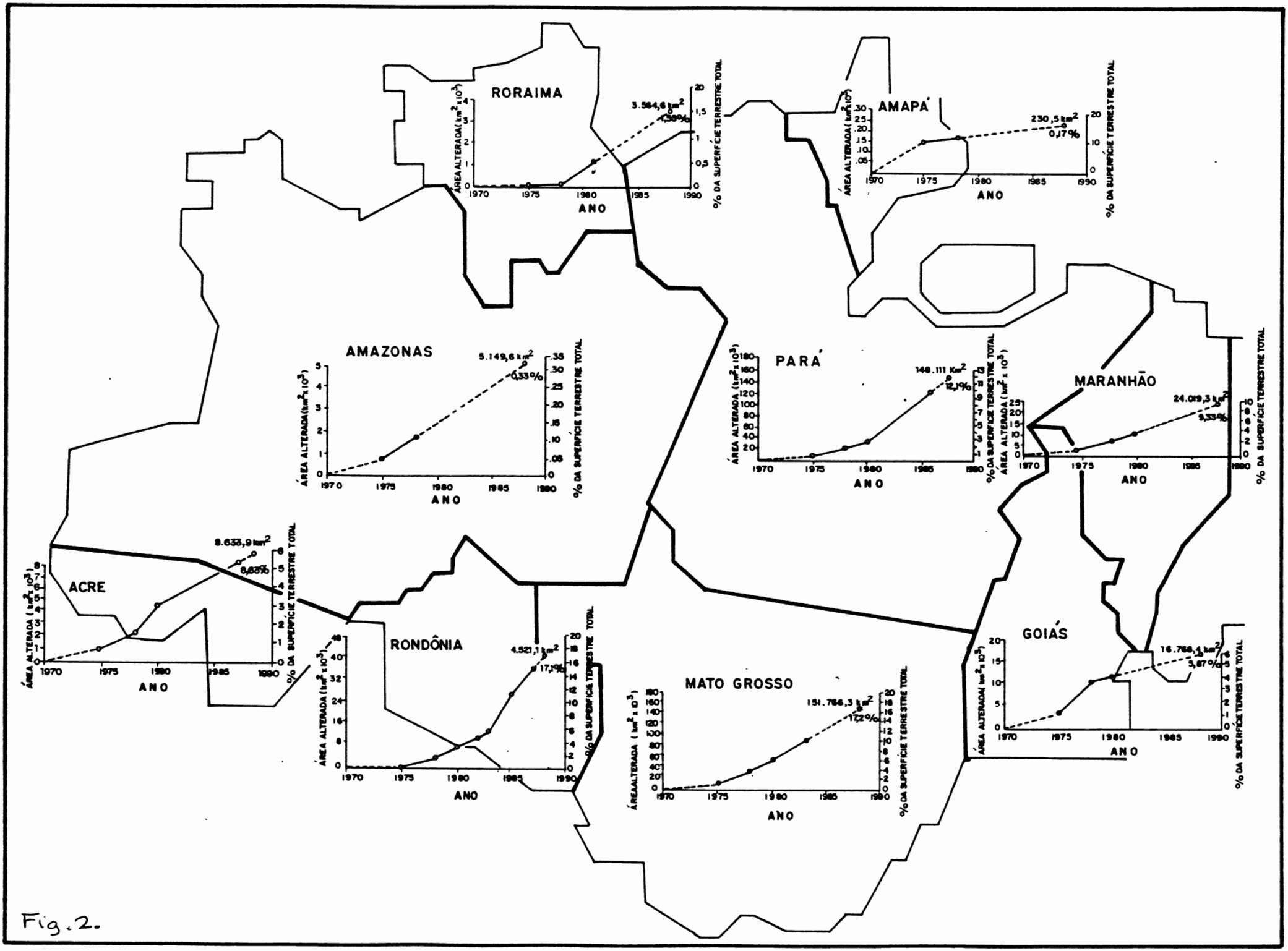
RORAIMA
3.564,6 km²
1,59%
AMAPÁ
230,5 km²
0,17%
AMAZONAS
5.149,6 km²
0,33%
PARÁ
148.111 Km²
12,1%
MARANHÃO
24.019,3 km²
9,33%
ACRE
8.633,9 km²
8,63%
RONDÔNIA
4.521,1 km²
17,1%
MATO GROSSO
151.766,3 km²
17,2%
GOIÁS
16.766,4 km²
5,87%
ÁREA ALTERADA (km² x 10³)
% DA SUPERFÍCIE TERRESTRE TOTAL
ANO
1970
1975
1980
1985
1990

Fig. 2.

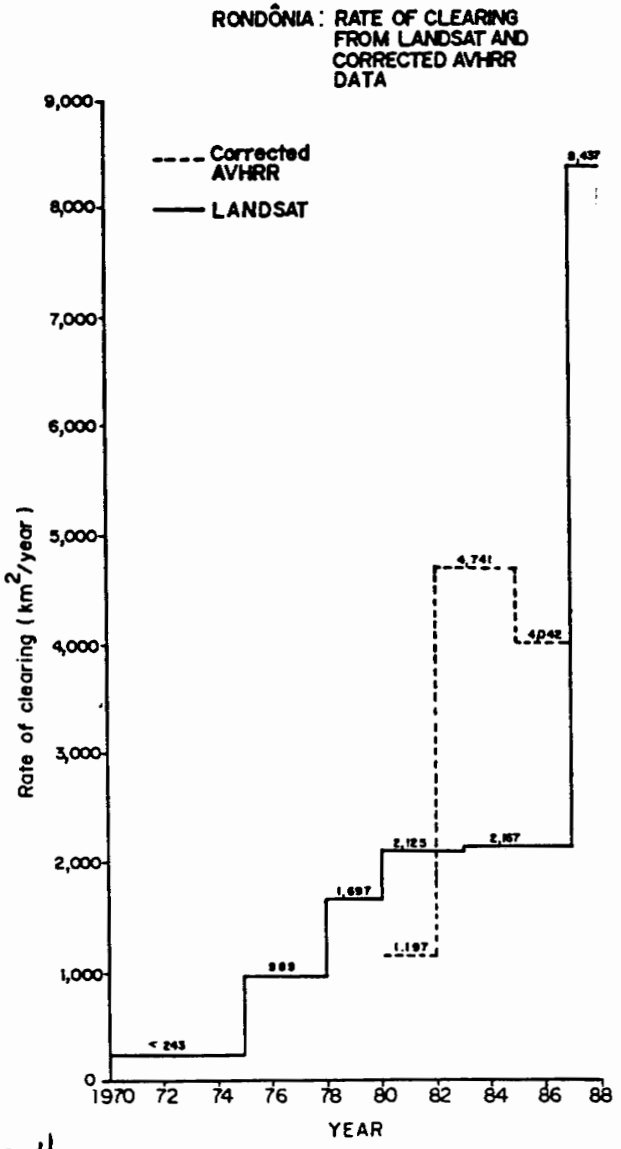
RONDÔNIA: RATE OF CLEARING FROM LANDSAT AND CORRECTED AVHRR DATA
Corrected AVHRR
LANDSAT
Rate of clearing (km²/year)
YEAR
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1970 72 74 76 78 80 82 84 86 88
< 243
889
1,697
2,125
1,197
4,741
4,042
2,167
8,437

Fig. 4.

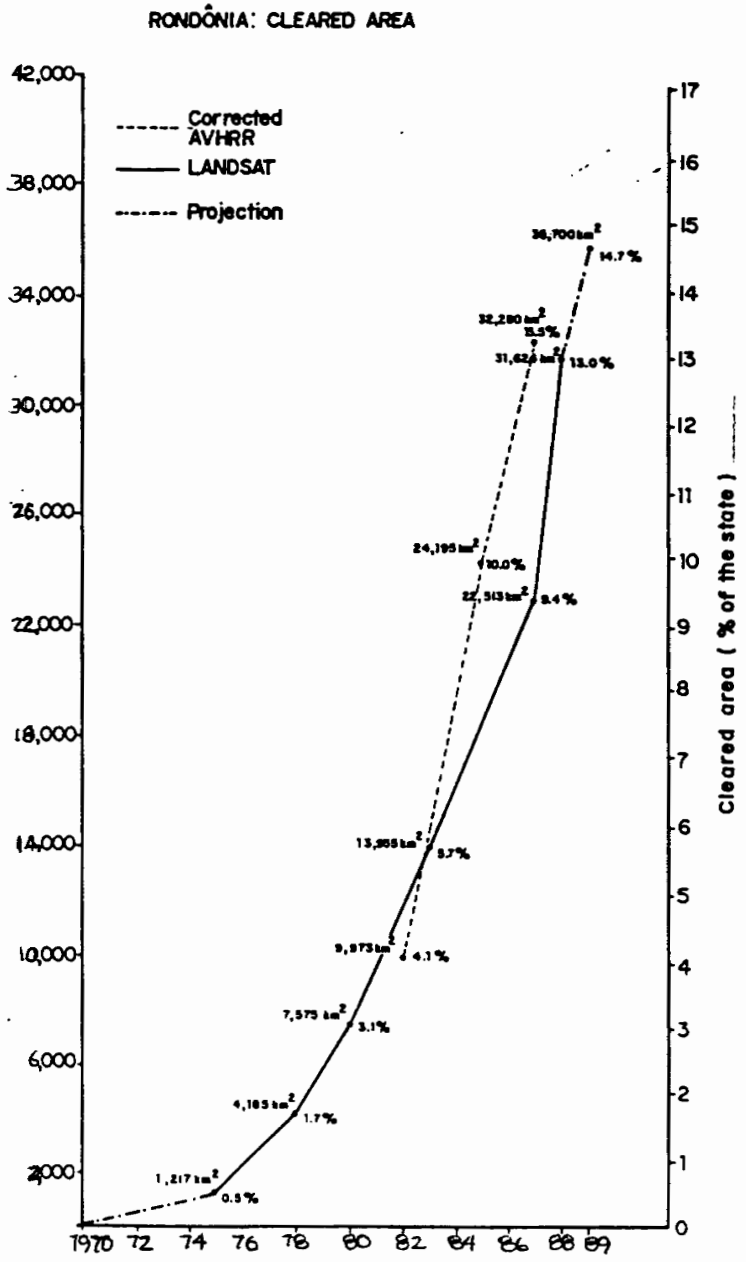
RONDÔNIA: CLEARED AREA
Corrected AVHRR
LANDSAT
Projection
Cleared area (% of the state)
42,000
38,000
34,000
30,000
26,000
22,000
18,000
14,000
10,000
6,000
2000
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1970 72 74 76 78 80 82 84 86 88 89
1,217 km²
0.5%
4,165 km²
1.7%
7,575 km²
3.1%
9,873 km²
4.1%
13,958 km²
5.7%
22,513 km²
9.4%
24,195 km²
10.0%
31,624 km²
13.0%
32,280 km²
13.3%
36,700 km²
14.7%

Fig. 3.